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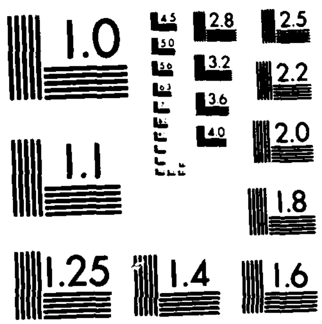

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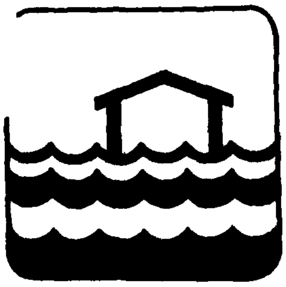
GREAT I
STUDY OF THE UPPER MISSISSIPPI RIVER

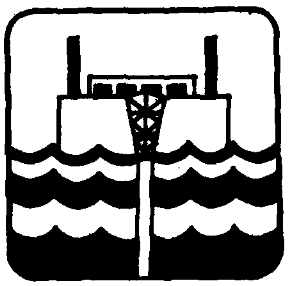
TECHNICAL APPENDIXES

VOLUME 2



FLOODPLAIN MANAGEMENT

DREDGED MATERIAL USES



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The GREAT River

1980

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Report 2 consists of three parts. Part A, dealing with floodplain management issues and concerns along the Mississippi River, from Minneapolis/St. Paul, Minnesota to Lock and Dam #10 at Guttenburg, Iowa, and the Minnesota and St. Croix Rivers.

Parts B and C deals with the costs of dredging operations, the environmental effects of dredging, and uses for dredged material.

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OUTLINE

GREAT I

SEPTEMBER 1980

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GREAT RIVER ENVIRONMENTAL ACTION TEAM
FLOODPLAIN MANAGEMENT WORK GROUP
FINAL APPENDIX

PREPARED BY:

MINNESOTA DEPARTMENT OF NATURAL RESOURCES
OFFICE OF PLANNING

PREPARED FOR:

GREAT RIVER ENVIRONMENTAL ACTION TEAM
AND
U.S. ARMY CORPS OF ENGINEERS - ST. PAUL DISTRICT

In partial fulfillment of
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FOREWORD FROM THE GREAT TEAM

This report was prepared by the Floodplain Management Work Group of the Great River Environmental Action Team (GREAT I). The conclusions and recommendations contained in this report reflect the work performed by this work group only, within its specific area of expertise. Recommendations from this report will be considered in relation to other objectives for overall resource management and may be included in the final GREAT I report as considered appropriate by the GREAT I Team.

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Note: Appendixes A, B, C, D, F, and G are on file with Planning Branch St. Paul District, Corps of Engineers, 1135 U.S. Post Office & Custom House, St. Paul, Minnesota 55101

I. GENERAL INTRODUCTION

A. Purpose of Appendix

This document has been prepared by the Floodplain Management Work Group of the Great River Environmental Action Team (GREAT I) as an appendix to the GREAT I final report.

From 1974 to 1980, the Floodplain Managment Work Group (FPMWG) addressed concerns related to floodplain management on the Upper Mississippi River 9-foot channel system from Minneapolis, Minnesota, to Guttenberg, Iowa. The major emphasis of the work group has been to develop input to the GREAT I channel maintenance plan. The work group has also addressed other issues related to a long-term management strategy for the river.

Although this document may represent the end of one chapter in the management of the Upper Mississippi River system, the task of achieving the preservation of this magnificent resource is only beginning.

B. Conclusions and Recommendations

Conclusions

1. The 1965 flood was accepted as the approximate regional flood for base mapping purposes.

2. The costs involved in producing topographic maps of the study area from recent air photos are beyond the budget limitations of GREAT I.

3. Any mathematical model used to determine river hydraulics with respect to flood flows should be an unsteady state model, incorporating the effects of floodplain storage.

4. Technical guidance will be sought from the Floodplain Management Task Force of the Upper Mississippi River Basin Commission (UMRBC). This task force has representatives from five States - Minnesota, Wisconsin, Iowa, Illinois and Missouri - and three Federal agencies.

5. Concerning effects of sedimentation on flood flows:

a. Wash load sediment (silts, clay, and organics) aggradation in the Mississippi River backwaters will not significantly affect flood storage or flood stages during the planning time frame of GREAT I.

b. Bed material load (sand) aggradation in the main channel and backwaters is likely to have an increasingly significant adverse impact on flood storage and flood flows during the planning time frame of GREAT I.

c. The FPMWG supports the efforts of the Sediment and Erosion Work Group to reduce the amount of bed material load entering the Mississippi River from tributaries. The flood-carrying capacity of the river would be maintained and potentially destructive increases in flood stages would be avoided.

6. The Compound Stream Flow Model, as applied in a pilot study in pool 4, can be used as an analytical and predictive tool for floodplain management.

Recommendations - (See Section VIII for implementation and rationale).

The following recommendations relate to the GREAT I channel maintenance plan and are based on work group objectives, review of potential placement sites, and conclusions reached by the work group:

1. The FPMWG recommends that, for every dredging cut in the GREAT I area, an out-of-floodplain placement site be identified and evaluated for comparison with other alternative sites.

2. Regarding selection of dredged material placement sites, the FPMWG recommends:

a. In every case where in-floodplain placement of dredged material is proposed, a quantitative analysis of the effects on the 1-percent chance flood be made. The analysis must include a computation of the effect of any encroachment into the floodway by assuming an equal degree of hydraulic encroachment on the other side of the river for a significant hydraulic reach. If the evaluation shows that hydraulic and hydrologic effects are within the limits of applicable State standards, the FPMWG will accept the site.

b. Until a quantitative analysis is conducted, placement sites be selected following these guidelines.

(1) Dredged material should be placed outside the floodplain of the Mississippi River and tributary streams.

(2) In those cases where in-floodplain placement is found to be necessary, material should be placed in the flood fringe rather than the floodway or effective flow area.

(3) Placement in the floodway or effective flow area is acceptable on a temporary basis. The material must be removed from the floodway before seasonal high water.

3. The FPMWG recommends that lands along the river that are suitable for stockpiling of dredged material and subsequent removal for beneficial use outside the floodplain be publicly acquired in fee title or easement.

4. The FPMWG recommends that the feasibility of removing material from existing placement sites in the floodway be investigated.

The following recommendations relate to future management and planning on the Upper Mississippi River and are proposed for implementation:

5. The FPMWG recommends that a computerized, hydrologic/hydraulic math model be developed to evaluate the impacts of long-term dredged material placement and other encroachment on the flood-carrying capacity of the Upper Mississippi River 9-foot channel project. The FPMWG supports the feasibility study for and ultimate development of math modeling for floodplain management purposes proposed by the UMRBC Floodplain Management Technical Task Force and supports efforts by the UMRBC to obtain funding for this project. On the basis of investigations conducted by the FPMWG, the Compound Stream Flow Model is suitable for this purpose and should be investigated as part of the feasibility study.

6. Projects in the Mississippi River 9-foot channel floodplain that involve an encroachment or loss of storage should be entered in the mathematical model identified in recommendation 5 to keep the data base current and ensure that cumulative effects of floodplain development are evaluated.

7. Uniform standards for floodplain management should be developed for States and municipalities along the GREAT I portion of the Mississippi River. Changes in enabling legislation may be necessary.

8. Detailed topographic and hydrographic maps of the Upper Mississippi River bottomlands in the GREAT I area should be produced. The maps should be at a scale no smaller than 1:12,000 (1 inch = 1,000 feet) on an ortho-photo base with contour intervals of 2 feet. The maps should be produced in a format facilitating their use by the general public. Costs of production should be recovered through sales of published maps to the general public.

9. Streambank erosion control measures should be implemented to reduce bed load sediment entering the Mississippi River from the Chippewa and Wisconsin Rivers, Wisconsin; Zumbro and Root Rivers, Minnesota; and Upper Iowa River, Iowa.

10. The FPMWG, in accordance with a recommendation of the Public Participation and Information Work Group, recommends that stream channelization or straightening projects that are proposed for tributaries of the Mississippi River in the GREAT I area be evaluated to determine:

a. Potential increases in tributary flood flows resulting from the project.

b. Potential increases in the bed load sediment transport capability of the tributary stream resulting from the project.

Floodplain Management Work Group
problems and accomplishments

Problems addressed	Accomplishment
1. Lack of floodway-floodplain mapping.	Floodplain and ordinance-designated floodway mapped on GREAT I Base Maps (see appendix E).
2. Lack of interstate consistency in definition of floodway.	FPMWG recommends development of consistent standards (see recommendation 7).
3. Need to determine effects of navigation project operation and maintenance on flood stages.	Math model pilot study conducted (see Sec. VI. B.) and math model development recommended (see recommendation 5).
4. Lack of recent and comprehensive topographic and hydrographic information.	Topographic mapping recommended (see recommendation 8) and cross-section data needs (Sec. VI. B.1.d.).
5. Need to determine effects of sediment buildup on flood stages.	No significant wash load effects expected during planning period (see conclusion 5 and Sec. VII. C.).

Floodplain Management Work Group
major accomplishments

Year	Accomplishment
FY 1975	Develop plan of action. Obtain new aerial photos - Hastings to Guttenberg. Obtain copies of aerial photos of 1965 flood.
FY 1976	Develop 1975 photo base maps. Draft floodplain maps on photo base.
FY 1977	Review potential dredged material placement sites. Initiate development of GREAT I base maps. Draft interim report appendix.
FY 1978	Review potential dredged material placement sites. Complete development of GREAT I base maps. Complete first draft of work group appendix.
FY 1979	Develop final floodway-floodplain maps on GREAT I base. Complete Pool 4 Math Model Pilot Study. Develop final conclusions and recommendations. Prepare final draft of work group appendix, including: effects of sedimentation on flood flows, legal and institutional framework, description of permit process.

Floodplain Management Work Group budget summary

Fiscal year	Project	Amount
1975	Aerial photographs, black and white on mylar, Hastings to Guttenberg	$5,800
	Copies of aerial photos of 1965 flood (two sets)	7,100
1976	Draft floodplain maps	
	Cartography	2,500
	Photo reproduction	2,300
1977	GREAT I base maps - cartography	11,700
1978	GREAT I base maps - cartography	6,500
	Work group chairman	25,000
	Floodplain mapping	8,000
	Math model pilot study, pool 4	10,300
1979	Work group chairman	25,000
	GREAT I base maps, photo reproduction	5,500
Total		109,700

II. WORK GROUP DESCRIPTION

A. Background

To develop a river system management plan that would incorporate total river resource requirements, the UMRBC adopted 12 objectives in fall 1974. These objectives were the framework for the formation of the Great River Environmental Action Team. Objective k. stated that GREAT was to "strive to comply with Federal and State floodplain management standards." When GREAT I was organized into work groups, the Floodplain Management Work Group was established to address this objective.

B. Objective, Purpose, and Tasks

The main objective of the FPMWG is to develop recommendations for dredged material placement and floodplain development that comply with State floodplain management standards. The purpose of the work group was to ensure that the final GREAT I report reflects floodplain management issues and concerns along the Mississippi, Minnesota and St. Croix Rivers.

The following tasks were assigned to the FPMWG in the 1975 GREAT I plan of study:

1. Delineate the floodway and floodplain of the Mississippi River system from the head of navigation to Guttenberg.

2. Compile and correlate State floodplain regulations, particularly with respect to floodplain encroachment stipulations.

3. Establish a screening process for evaluating dredged material placement sites and floodplain development according to floodplain encroachment regulations and other floodplain management objectives.

4. Draft floodplain management appendix.

By completing these tasks the FPMWG would produce components of the final GREAT I report.

C. Scope

The FPMWG has decided to address those floodplain management issues which directly relate to GREAT I channel maintenance or other proposed development plans. It has not developed comprehensive floodplain management policies or plans to control river valley land use. The work group members believe that existing programs of State and local government will accomplish comprehensive floodplain management. The FPMWG has made every effort to conduct its activities in accordance with the goals and procedures of these established programs.

D. Organization, Membership, and Procedures

The Minnesota Department of Natural Resources (MDNR) provided the leadership for the FPMWG. A full-time chairman from the MDNR has served since October 1974. From 1974 to 1977, the chairman position was continued with State funds. During fiscal years 1978 and 1979, the chairman was funded from GREAT I funds. The chairman has coordinated the activities of the FPMWG with those of other work groups and served as a member of the Plan Formulation Work Group.

The membership of the FPMWG has always been open to anyone with an interest in the objectives of the work group. At the conclusion of GREAT I, 31 people were on the work group roster. Active membership included representatives from the Iowa Natural Resources Council, Minnesota Department of Natural Resources, Wisconsin Department of Natural Resources, Corps of Engineers, Fish and Wildlife Service, and the GREAT I Public Participation Work Group. Technical Appendix A contains a list of work group members.

The FPMWG has met periodically during the GREAT I Study since 1974. Meetings were called by the work group chairman and averaged four per year from 1974 to 1977 with 10 meetings in 1978. The chairman served as moderator of the meetings and recorder of the minutes. Technical Appendix B contains minutes of all work group meetings.

Voting on the work group has been by consensus, following the format of the GREAT I Team. Each participant at the meetings was allowed one vote.

E. Public Participation

The membership of the FPMWG has been open to all who wish to participate - including the general public. Most of the work group meetings have been attended by a member of the Public Participation and Information Work Group.

Work Group representatives attended GREAT I Town Meetings in 1975 and 1977. At those meetings, the public was invited to comment on the work group plan of action and offer suggestions for future studies.

During a series of workshops held in January 1979, the work group chairman presented work group conclusions and recommendations to the Public Participation and Information Work Group Executive Board. Board members provided input to formulation of recommendations appearing in this report. Recommendation 10 was based on information provided in the board's position paper.

III. PROBLEM IDENTIFICATION

A. Procedure

The primary problem addressed by the work group has been the environmentally unsound placement of material dredged by the Corps of Engineers for channel maintenance. GREAT I was formed primarily to address and solve this problem. The FPMWG has directed its efforts to alleviating floodplain management problems associated with dredged material placement.

In March 1976, GREAT I work groups were instructed to identify all problems and needs related to their areas of expertise. These problems and needs were identified by work group members, management and planning documents, and people attending the town meetings.

The GREAT I Team developed a set of guidelines to determine which problems and needs fell within the scope of the Great River Study. The FPMWG evaluated each problem or need according to the guidelines to determine whether the problem should be addressed by the Team. In some cases, issues raised were not addressed by the FPMWG because other established programs or agencies were working on them. The FPMWG also assigned each problem or need to a short- mid-, or long-term time frame. The time frame indicated whether the problem could be expected to be solved or the need met within a few years or within a longer time period.

Table 1 lists the problems identified; indicates whether they were addressed by the work group and the time frame and priority that were assigned; and explains why a problem or need was, or was not, addressed.

Table 1 - Floodplain Management Work Group

Problem	Should problem be addressed by GREAT?	Work Group?	Time Frame(1)	Priority	Rationale
1. Lack of floodway-floodplain mapping.	Yes	Yes	S	1	To determine encroachment of dredged material and development on the floodplain and floodway, these features must be mapped. The work group is pursuing this problem through a base mapping program.
2. Lack of interstate consistency in definition of floodway.	Yes	Yes	M	2	State interpretations of the river floodway are different. A common definition of floodway must be developed to undertake a floodway mapping program.
3. Need to determine effects of navigation project operation and maintenance on flood stages.	Yes	Yes	M	3	A difference of opinion exists among various agencies as to the effects of dredging and placement on flood stages.
4. Lack of recent topographic and hydrographic information.	Yes	Yes	L	4	Detailed cross-section data are needed for detailed engineering studies to determine encroachment effects on flood stages. It is recognized that time and money constraints of GREAT may preclude development of a complete cross-section program. However, the work group will address the need for such data.

Table 1 - Floodplain Management Work Group (continued)

Problem	Should problem be addressed by GREAT?	Work Group?	Time Frame(1)	Priority	Rationale
5. Need to determine effects of sediment aggradation on flood stages.	Yes	Yes	L	5	The effects on flood stages caused by loss of storage as the pools fill in with sediment are not known. While a study of this problem would not be directly related to the mission of the work group, it may still be possible to address this issue to some degree.
6. Need to determine effect of County State Aid Highway 24 and Zumbro levee on flood stages.	No	No	-	-	While this problem has interagency and interstate implications, a framework exists for the Corps of Engineers and Minnesota and Wisconsin Departments of Natural Resources to deal with this problem. Criteria preclude GREAT intervention if capability exists in agencies to deal with the problem.
7. Effects of locks and dams on flood stages.	No	No	-	-	The Corps of Engineers has already addressed this problem. See reference 2.
8. Discrepancies in flood damage potential determinations need to be addressed.	No	No	-	-	An adequate legal and institutional framework exists to address concerns related to this problem. GREAT could not contribute appreciably.

Table 1 - Floodplain Management Work Group (continued)

Problem	Should problem be addressed by GREAT?	Work Group?	Time Frame(1)	Priority	Rationale
9. Need for a Mississippi River floodplain management plan and changes in regulations required by the plan.	No	No	-	-	Not within the scope of GREAT. (See rationale for 8.)
10. Problem in interpretation of project benefits where development potential is included.	No	No	-	-	(See rationale for 8.)
11. Flood transported debris is blocking some backwater areas.	Yes	No	-	-	Where recreational navigation is appreciably disrupted, this problem can be considered by the Fish and Wildlife Work Group.

(1) S= Short (1-5 years), M = Mid (5-25 years), L = Long (25-50 years).

B. Most Probable Future

The U.S. Water Resources Council adopted principles and standards to guide all federally funded water resource planning. GREAT I must comply with these guidelines and procedures.

To provide a bench mark against which to measure the effectiveness of recommendations, the principles and standards require the description of a Most Probable Future (MPF). The MPF is the planner's best estimate of what future conditions would be if a project or management program were not implemented. It is largely a hypothetical conclusion, based on valid assumptions plus historical record. Any improvements over the MPF resulting from a project are to be considered benefits of that project.

With this background, the FPMWG has identified several MPF conditions which relate to floodplain management. These conditions would probably exist on the Upper Mississippi River in the GREAT I area during the next 50 years.

1. The floodplain of the Upper Mississippi River would not be mapped except in urbanized areas. The hydraulic-engineered floodway of the river would not be designated except in urban areas where flood insurance studies are carried out. Implementation of county zoning ordinances to control floodplain development would be less effective along the river because of a lack of definition of the floodplain and floodway limits.

2. The Corps of Engineers would continue to place dredged material in the floodway and floodplain of the river except in some urban areas, such as the Twin Cities. Even where some of the material will be used out of the floodplain, during low demand periods, material would have to be placed in the river. In many cases, such encroachment would impede the flood-carrying capability of the river. The result would be higher flood stages.

3. Some local or State governments would bring legal action against the Corps of Engineers as a result of flood damages attributable to dredged material encroachment.

4. Floodplain management programs would continue to be administered without interstate coordination or standardization. Analysis of site-specific encroachments would continue to be made without considering the opposite bank impacts or the long-term cumulative effects.

5. The technology to detect the effects of encroachments or other floodplain development on floods will probably improve.

6. There will probably be at least a 50-year frequency (2-percent chance) flood. Such a flood would measure approximately 127,000 cfs (cubic feet per second) at St. Paul, Minnesota, and 210,000 cfs at Winona, Minnesota, using the latest discharge-frequency relationships.

IV. LEGAL AND INSTITUTIONAL FRAMEWORK

A. Federal and State Framework

Floodplain management in the GREAT I area is accomplished within a well-defined legal and institutional framework. This section describes this framework in terms of the laws, primarily Federal and State, that provide for floodplain management and the agencies responsible for their implementation and enforcement. The status of floodplain management at the local level is also described. Most of the information presented here is taken from the following two documents, prepared specifically for GREAT: Cook, Jeff, Flood Plain Policy, Legislation and Regulations Concerning the Upper Mississippi River Area, unpublished draft (Iowa Geological Survey, September 1978) and Stewart, Susan M., State and Federal Restrictions on Dredge Spoil Placement in the Upper Mississippi River Area, (Iowa Geological Survey, May 1978).

1. Federal Laws and Agencies

As development and urbanization of floodplains along the Nation's watercourses increased, so did property damage and loss of life as a result of floods along those streams and rivers. Congress responded to the need for protection from flooding by enacting a series of "Flood Control Acts" beginning in 1917. These acts authorized the Corps of Engineers to construct levees and reservoirs to contain floodwaters and protect people and property. Until the late 1960's, the Federal Government maintained a policy which advocated structural solutions to flood problems.

However, flood damages often increased because many levees and dams became ineffective when watershed characteristics changed.

The levees and dams had provided a sense of security and actually encouraged floodplain development. When later floods overtopped the levees and when dams failed or were unable to contain the runoff from large storms, the damages were greater than might have occurred without the structures.

a. National Flood Insurance Act of 1968

The Federal Government recognized that structural measures were not the best way to deal with increasing flood losses. In 1968, Congress enacted the "National Flood Insurance Act of 1968." This act emphasized the use of nonstructural measures to reduce flood damages. The act was designed to implement a floodplain management program which would discourage construction in flood prone areas. The Federal Insurance Administration (FIA) delineates flood hazard areas, establishes minimum performance standards for local ordinances, provides technical assistance to communities, and, where necessary, subsidizes insurance underwriting.

Communities desiring to participate in the National Flood Insurance Program are required to adopt a local ordinance regulating development in floodplain areas identified by the FIA. Incentive for communities to enter the flood insurance program was provided by the Congress in passing the "Flood Disaster Protection Act of 1973." The Act required communities in flood prone areas to participate in the flood insurance program if they wanted to continue receiving Federal funding for development and disaster assistance in flood-hazard areas and to be eligible for flood insurance.

For communities having flood damage potential, the FIA will prepare a flood hazard boundary map and a flood insurance rate map.

To enter the flood insurance program, communities must meet certain requirements for regulating development in the floodplain.

The local ordinance requires elevation of structures above flood levels, restrictions on watercourse relocation, restrictions on mobile home development, flood proofing, and prohibition of encroachments that would increase flood levels.

Studies required to develop the flood insurance rate map and floodplain-floodway map for a community are usually contracted out to consultants. The status of community involvement in the flood insurance program in the GREAT I area is described in sections describing the State framework.

b. Disaster Relief Act of 1974

The "Disaster Relief Act of 1974" provides for Federal assistance to victims of disasters or catastrophes, including floods. This act gives additional support to the flood insurance program. It requires that Federal disaster relief for flood damage be withheld from eligible communities not participating in the flood insurance program. Communities that enter the program within 6 months of the filing of the Federal damage survey report become eligible for disaster relief. However, a community that drops out of the program after having applied once is not eligible for reentry to the program to cover after-the-fact damage.

c. Executive Order 11988

Executive Order 11988, issued by President Carter in May 1977, provides direction to Federal agencies concerning their activities in floodplain areas. The objective of the order is to avoid

the adverse impacts of modification of floodplains and to avoid spending Federal money to support development in floodplains where practical alternatives exist.

The order requires Federal agencies to reduce flood risk and losses and restore natural floodplain values in all management, construction, and land use activities on Federal lands. Agencies must determine if their actions will have direct or indirect impacts on floodplains. For in-floodplain proposals, an out-of-floodplain alternative must be formulated and evaluated. The floodplain is considered to be the area inundated by the 1-percent chance (100-year) flood. Any construction or development in the floodplain must comply with the requirements of the National Flood Insurance program. (This executive order is discussed in more detail in Sec. IV B.)

d. 1960 Flood Control Act

In 1960, Congress authorized the Corps of Engineers to provide technical information to States to aid them in regulating floodplains. In most cases, this assistance comes in the form of floodplain information reports that provide basic data on the hydrology and hydraulics of streams in communities. In recent years, Minnesota has used this money for projects to help local governments administer their floodplain ordinances including educational manuals and flood hazard analyses.

e. Water Resources Planning Act of 1965

The Water Resources Planning Act of 1965 was passed as a declaration of congressional policy encouraging "conservation, development and utilization of water and related land resources of the United States." This act established the regional river basin

commissions and also set up the Water Resources Council (WRC) to implement certain provisions of the act. The WRC has established principles, standards, and procedures for development of Federal water resource projects and comprehensive land and related water resource management plans.

The WRC has established guidelines for determining frequency-discharge relationships in streamflow. These guidelines have been published and periodically updated. The first publication was Bulletin 15 issued in December 1967. Bulletin 17 was issued in March 1976, and Bulletin 17A was issued in June 1977. All Federal agencies and federally sponsored projects dealing with flood control or flood damage reduction must conform to the procedures described in the bulletins. In addition, WRC has recommended that State and local governments and private engineers apply these procedures to their studies of flood flow frequency.

f. Corps of Engineers Permit Authority

Under two separate Federal acts, the Corps of Engineers is authorized to require permits for certain actions in the navigable waters of the Nation. This authority has broad implications for regulation of activities in floodplain areas.

Section 10 of the "River and Harbors Act of 1899" gives the Corps of Engineers permit authority for structures or development in navigable waters.

Section 404 of the Water Pollution Control Act Amendments of 1972" authorizes the Corps of Engineers to issue permits for the discharge of dredged or fill material into navigable waters. Since passage of the act, the concept of navigable waters has been expanded to cover almost all waters of the Nation. In

deciding whether to issue permits, the Corps is to consider probable beneficial or adverse effects of the activity, the public or private need, and the cumulative effects. Based on the nature of the activity, permits are issued on a general or individual basis. The Environmental Protection Agency and Corps of Engineers guidelines for issuing these permits have been jointly prepared.

2. State Laws and Agencies

Ideally, floodplain management concerns land use and development control. The objective is to restrict development in floodplain areas to those uses that are compatible with the primary purpose of the floodplain - conveyance of flood flows.

The U.S. Constitution gives the responsibility and authority for land use control to the States. The States' police powers are directed at promoting health, safety, and general welfare. Land use control in floodplain areas is interpreted as being consistent with this responsibility.

To implement floodplain land use controls, States in the GREAT I area have enacted enabling legislation which delegates implementation and enforcement authority to local units of government. The enabling legislation established guidelines, rules, and regulations which the local units must meet in developing local land use control ordinances. The States retain authority to act where local units fail to adequately adopt or enforce the State-approved ordinances.

Land use and development in floodplains are controlled by one or more types of regulatory provisions - zoning ordinances, subdivision regulations, sanitary controls, and building codes.

a. Iowa

According to Iowa law, the floodplain is the area adjacent to a stream or river that has been or may be covered with floodwater (IAC 455A). The Iowa Natural Resources Council (INRC) has broad responsibility for management of Iowa's floodplains. The INRC may establish floodplain development regulations, encroachment limits, and minimum protection levels appropriate to a stream or river.

IAC 455A also requires the INRC to regulate floodplain development through a permit process. A permit is issued if a project meets certain criteria regarding protection levels and backwater effect. The INRC can require removal of unpermitted floodplain construction if notification is made within 1 year after completion of the project. Development that would obstruct flow is not allowed in floodways.

Local units of government may adopt ordinances controlling floodplain development. INRC permits are not required for construction in floodplain areas complying with a State-approved local floodplain ordinance. Local ordinances must contain several elements to be approved by the INRC. Encroachment limits defining the floodway are based on a maximum rise of 1 foot for the 1-percent chance (100-year) flood. In locating encroachment limits, existing buildings should not be contained in the floodway, and further increases in flooding from new buildings should be avoided. The concept of equal degree of hydraulic conveyance is to be applied in locating encroachment limits.

Before assistance was provided to local governments for floodplain studies under the National Flood Insurance Act of 1968, adoption of local floodplain management ordinances in Iowa was sporadic. *The flood insurance program* has provided the impetus to local Iowa communities to adopt ordinances. Floodplain information developed under this program must be approved by the INRC before the local ordinance on which it is based is legally enforceable.

The State of Iowa also has regulatory jurisdiction over all navigable waters and adjacent lands up to the ordinary high-water mark. The Federal Government retains control over water use for navigation interests. Property formed by artificial accretion, such as dredged material placement, belongs to the riparian land-owner. The Iowa Conservation Commission (ICC) has regulatory authority over the State's public waters.

An ICC permit is required for any development or construction in State waters or below the ordinary high-water mark. The only activities exempt from this requirement are construction of mill-dams and flood control projects. In addition, the ICC may require removal of construction from areas within its jurisdiction if the removal is judged to be in the best interests of the State.

The ICC also has some control over use of land adjacent to streams if the stream is designated a scenic river according to the Scenic Rivers System Act. Local units of government having jurisdiction along such a stream must adopt ordinances to preserve the scenic chara(:r by controlling development. The Upper Iowa River in the GREAT I area has been so designated.

As was mentioned above, local units of government in Iowa are given authority under State law to adopt floodplain zoning ordinances. Before an ordinance is enforceable, it must be approved by the INRC. None of the local units in the portion of Iowa in the GREAT I study area have adopted INRC approved ordinances as of this writing. However, flood prone areas have been identified in all Iowa municipalities in the GREAT I area, including Allamakee and Clayton Counties, Iowa. The following Iowa county and communities in the GREAT I area have entered the flood insurance program to date: Clayton County, Clayton, Marquette, McGregor and Guttenberg.

b. Minnesota

In April 1969, the Minnesota legislature enacted the "Flood Plain Management Act." (M.S. 104) The act was intended to discourage floodplain development in the first place rather than trying to provide flood protection as development progresses. This act serves as enabling legislation for local units of government to adopt non-structural means to manage floodplains.

Minnesota counties, cities, and towns where flooding hazards exist are required to adopt and enforce floodplain management ordinances. The MDNR is responsible for ensuring local government compliance with the requirements of the act. In accordance with the act, the MDNR published "Statewide Standards and Criteria for Manage-

ment of Flood Plain Areas of Minnesota" in 1970 (Minn. Reg. NR85 et seq.). These guidelines describe standards to be met by local ordinances. Ordinances are subject to MDNR approval after the MDNR determines that sufficient technical supporting data are available. A 1973 amendment to the 1969 act established a time frame within which the MDNR will adopt an ordinance for a local unit that meets the minimum standards if that unit fails to adopt its own ordinance.

In the development of a local floodplain management ordinance, MDNR rules require two basic determinations. First, the area that would be covered by the regional flood (1-percent chance occurrence) must be identified. This information may be obtained from several sources; however, it frequently comes from flood insurance studies conducted by the Federal Insurance Administration. The floodplain may then be divided into a floodway and flood fringe. The floodway and flood fringe concepts are further defined in Section V.B.1. of this report. State law generally allows floodplain encroachments up to a limit of 0.5 foot of flood stage increase. However, the commissioner of the MDNR may be more or less restrictive in enforcing this limit, depending on project-specific circumstances. In some cases, ordinances are adopted on the basis of identification of a general floodplain district. In this case, each proposed development of the district must be analyzed to determine its effects on flood elevations.

The local ordinance will specify what activities are appropriate for the identified areas of the floodplain. Floodway development is restricted to those projects or land uses that have low damage potential. Development in the flood fringe is generally allowed if structures are protected against floodwaters by elevating on fill or flood proofing. However, the MDNR generally discourages construction of buildings in floodplains.

As of September 1980, the following counties and communities in the Minnesota portion of the GREAT I study area did not have approved floodplain ordinances: Washington County, Dakota County, Brownsville, Minnieska, Kellogg, and Minnesota City. The city of Dakota in Winona County and Oak Park Heights in Washington County have ordinances that have not been officially approved by the MDNR. The studies that will result in ordinances, however, are well under way in Washington and Dakota Counties.

As of May 1980, Oak Park Heights in Washington County and Kellogg in Wabasha County were the only municipalities in the Minnesota portion of the GREAT I study area that were not participating in the Federal flood insurance program.

In Minnesota, the MDNR also has jurisdiction over development in the public waters of the State. If the water is navigable by Federal definition, the State owns the bed and the water over it. Public trust waters are further defined by determining if the water and surrounding land can be used for noncommercial benefit. These waters are protected by State Law.

Any operation in the beds of public waters that would change the course, current, or cross section of that stream or lake cannot occur without a written MDNR permit. These permits are authorized under Minnesota Statutes, Chapter 105.42. In deciding whether to issue a permit, the MDNR considers impacts of the project on fish and wildlife habitat, water pollution, and impacts of any future development resulting from the project. The proposed project must be consistent with existing land use programs. Alternatives to the project that have less impact are to be considered also.

If the alteration is placement of fill from a dredging operation, permit rules specify that dredged material should not be placed in the floodway of a stream or river. The emphasis of the water resources permit program is to "conserve and utilize the water resources of the state in the best interest of its people." (2 S.R. 2051) The proposed development must be consistent with other Federal, State, and local regulatory programs such as floodplain management, scientific and natural areas management, boat and water safety, and recreational or wilderness management.

Minnesota also has a shoreland management program that regulates development of defined floodplain areas and other shoreland areas of the State. Regulations developed under this program provide for building setback requirements, minimum lot sizes per structure, building elevation above high water, and sewage system design criteria. Shoreland management is implemented through adoption and enforcement of ordinances by local units of government.

c. Wisconsin

The floodplains of Wisconsin are protected from indiscriminate development at both the State and local government levels. The "Water Resources Act of 1965" served as the enabling legislation for local governments to adopt floodplain management ordinances in accordance with State guidelines. Chapter 87.30 of Wisconsin law requires counties and incorporated municipalities to adopt ordinances controlling land use in floodplain areas when sufficient hydraulic and engineering data are available. If the local unit of government fails to act, the Wisconsin Department of Natural Resources (WDNR) has authority to formulate an ordinance and require its enforcement.

The standards for the ordinances have been developed by the WDNR. These standards essentially rule out placement of fill material in floodways. The regulations prohibit any floodplain

development that would result in flood stage increases greater than 0.1 foot, unless arrangements can be made with affected landowners. Development in flood fringe areas is acceptable as long as floodplain storage is not reduced and the project is consistent with local plans. Wisconsin regulations define the floodway as the area of the floodplain necessary to discharge the regional flood (NR 116.03(15)). However, floodway limits may be determined from maps, vegetation, aerial photographs, and hydraulic analyses or engineering studies of prior flood events.

Floodway uses are generally restricted to low damage potential types such as agriculture, recreation, parking, and storage yards. Structures allowed in flood fringe areas must be elevated on fill so that the first floor is at least 2 feet above the regional flood elevation. Other regulations deal with reconstruction of flood-damaged structures; storage of hazardous substances in floodway areas; and flood proofing of commercial structures and public utilities, streets, and bridges. Wisconsin law emphasizes that floodplain management laws are designed to protect people, not floodplains.

All Wisconsin counties and municipalities in the GREAT I area have adopted floodplain management ordinances. All eligible communities and counties have entered the Flood Insurance Program on a regular or emergency basis.

Wisconsin law provides for riparian ownership of streams. However, riparian owners take title subject to the public trust doctrine which requires the State to hold in trust for each citizen all the navigable waters of the State. The riparian owner is granted some limited rights, but the State maintains regulatory authority over any stream bed development. Wisconsin Statutes Chapter 30 provides the WDNR with authority to prohibit placement of fill, including dredged material, below the ordinary high-water mark of public waters. The high-water mark is determined on the basis of vegetative characteristics of an area. The law does provide for

fill below the ordinary high-water mark if it is placed behind an approved bulkhead line designed to regularize the shoreline.

Wisconsin also has a shoreland management program to control development along shorelands of lakes and streams. Counties must adopt and enforce ordinances that meet State-established standards. These standards define minimum allowable lot sizes, building setback minimums, limits on vegetative removal, and sanitary system location and design.

B. Executive Order 11988

Presidential Executive Order 11988 concerning floodplain management was issued on 24 May 1977 (see Technical Appendix C). The order is designed to avoid the adverse impacts of floodplain development. It draws attention to the significance of floodplain areas and requires that out-of-floodplain alternatives be considered in development planning. Consideration must be given to the out-of-floodplain alternative which is least expensive.

The FPMWG analyzed this order to determine its implications for the GREAT I study. First, in developing channel maintenance plans, GREAT I must evaluate a placement site that is out of the floodplain in every case where in-floodplain placement is an alternative. If several nonfloodplain placement sites are available, the one selected should be the least costly to use. In those cases where in-floodplain placement is the only feasible alternative, guidelines accompanying the executive order require a quantitative analysis. Usually this analysis will be a hydraulic model describing flood stage increases that could result from the placement.

For any proposed Federal action that involves commitment of floodplain lands, the nonfloodplain alternatives must be considered. This provision of the executive order would apply to in-floodplain development proposals of other GREAT I work groups and to the placement of dredged material.

C. Permit Process

Local units of government, States, and Federal agencies recognize the need to regulate development in floodplains. Various laws have been enacted to give all levels of government this power. In most cases, a person wishing to develop floodplain lands must obtain a permit, or permits, from regulatory agencies before work can begin.

On the Mississippi River, where so many different jurisdictions overlap, the average citizen wishing to modify his property is often overwhelmed by the process he must go through to get permission. At public meetings the GREAT I Team has held along the river, citizens requested guidance on the

permit process. The FPMWG prepared the following flowcharts to illustrate the procedure. For the purposes of this illustration, the situation is that a private landowner wishes to obtain Corps of Engineers dredged material to fill some of his property along the Mississippi River in the GREAT I area. Other types of floodplain or shoreland development may require an entirely different type of review.

Figure 1. Iowa local and State permit process.

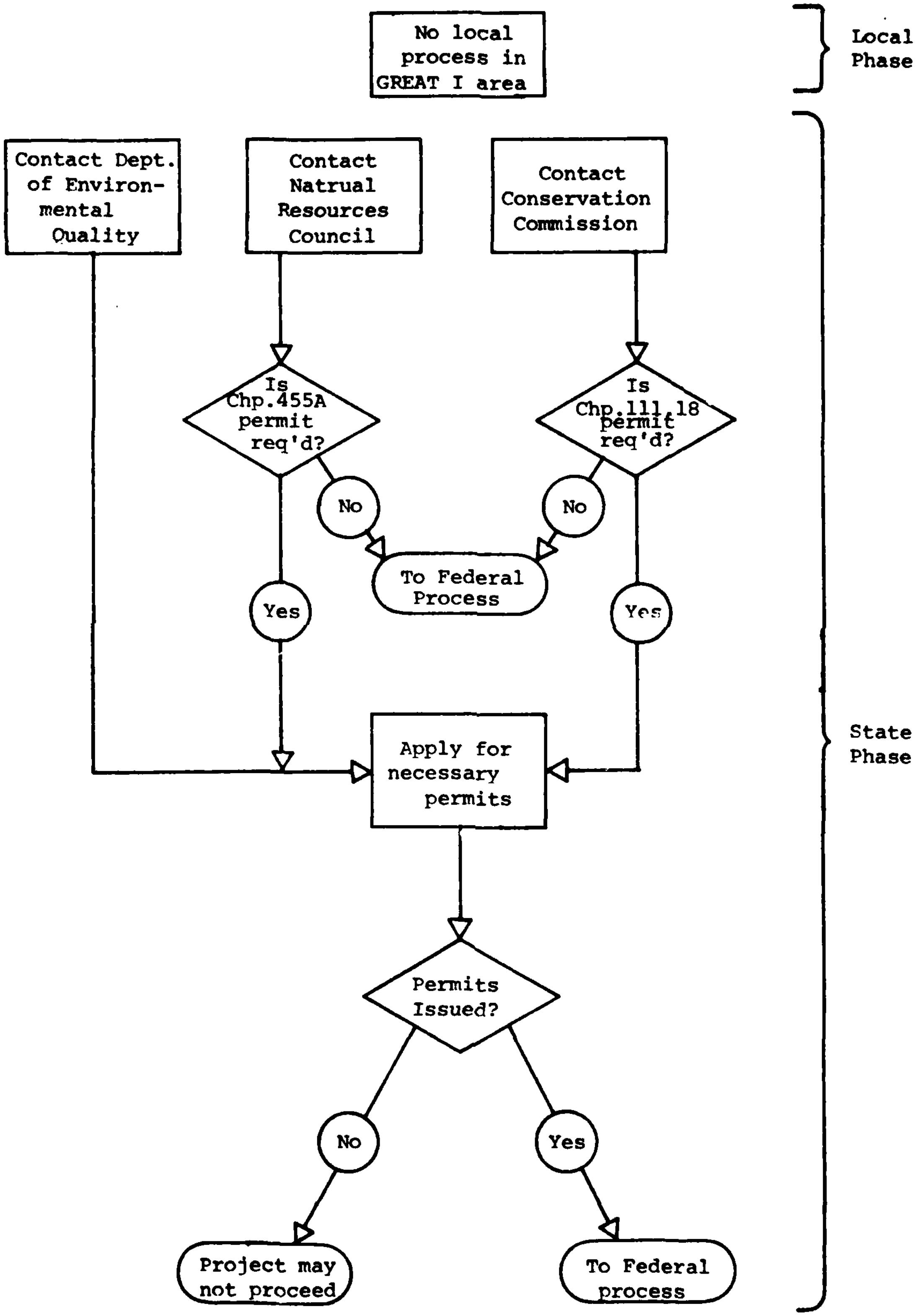


Figure 2. Minnesota local and State permit process.

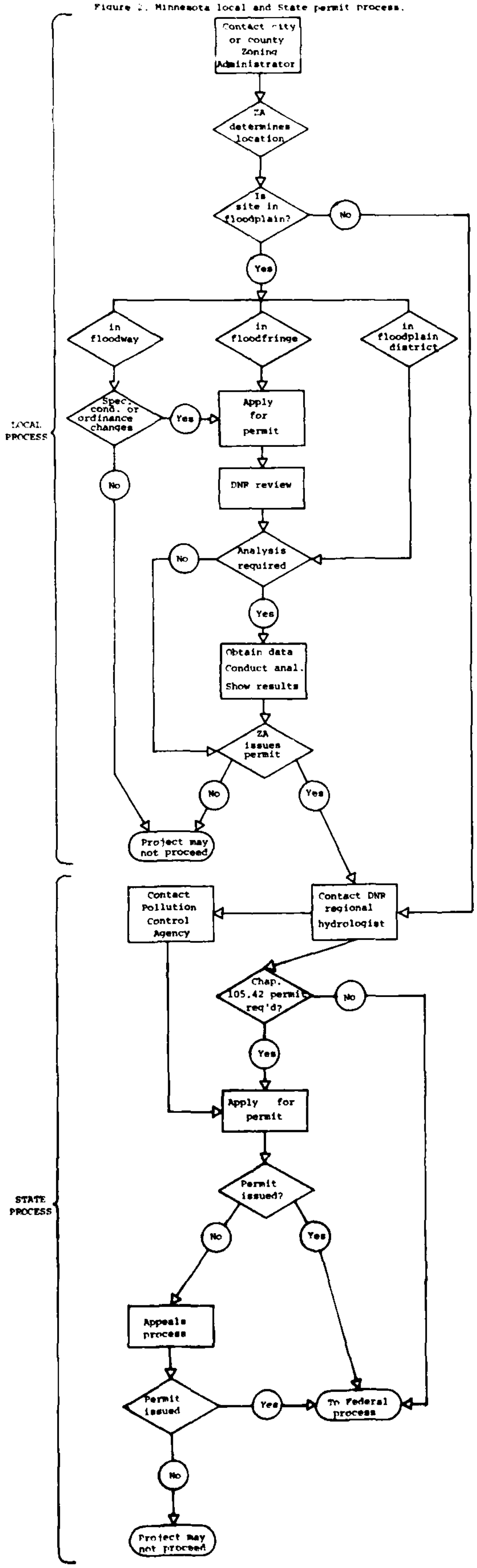


Figure 3. Wisconsin local and State permit process.

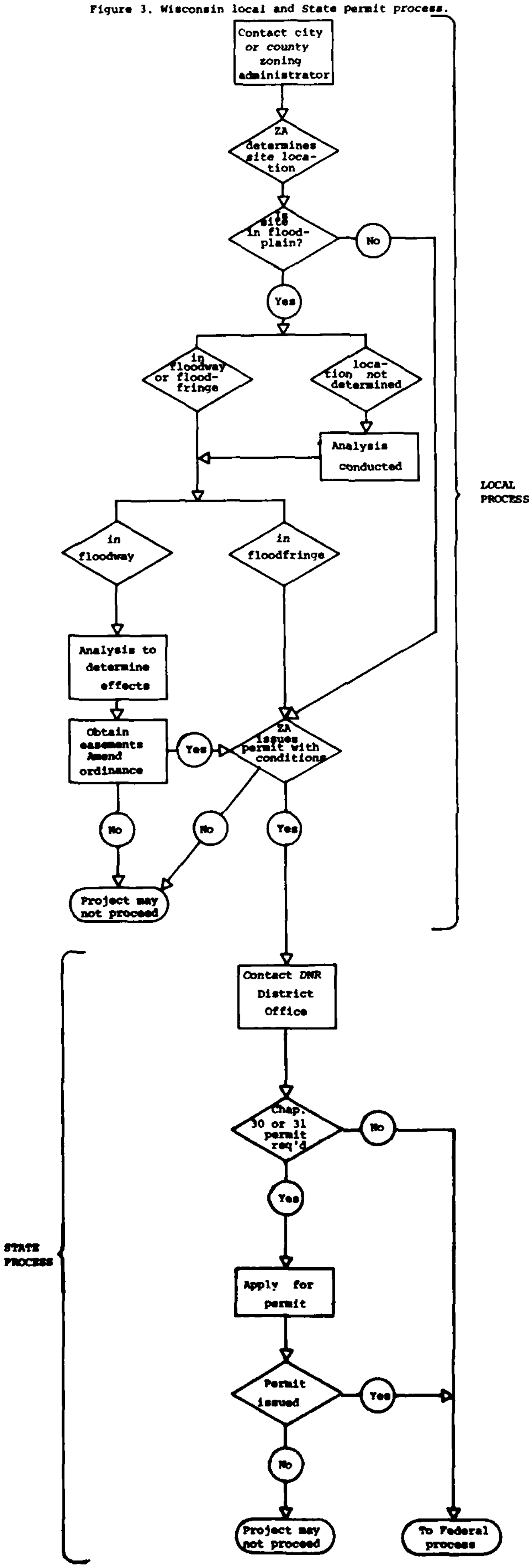
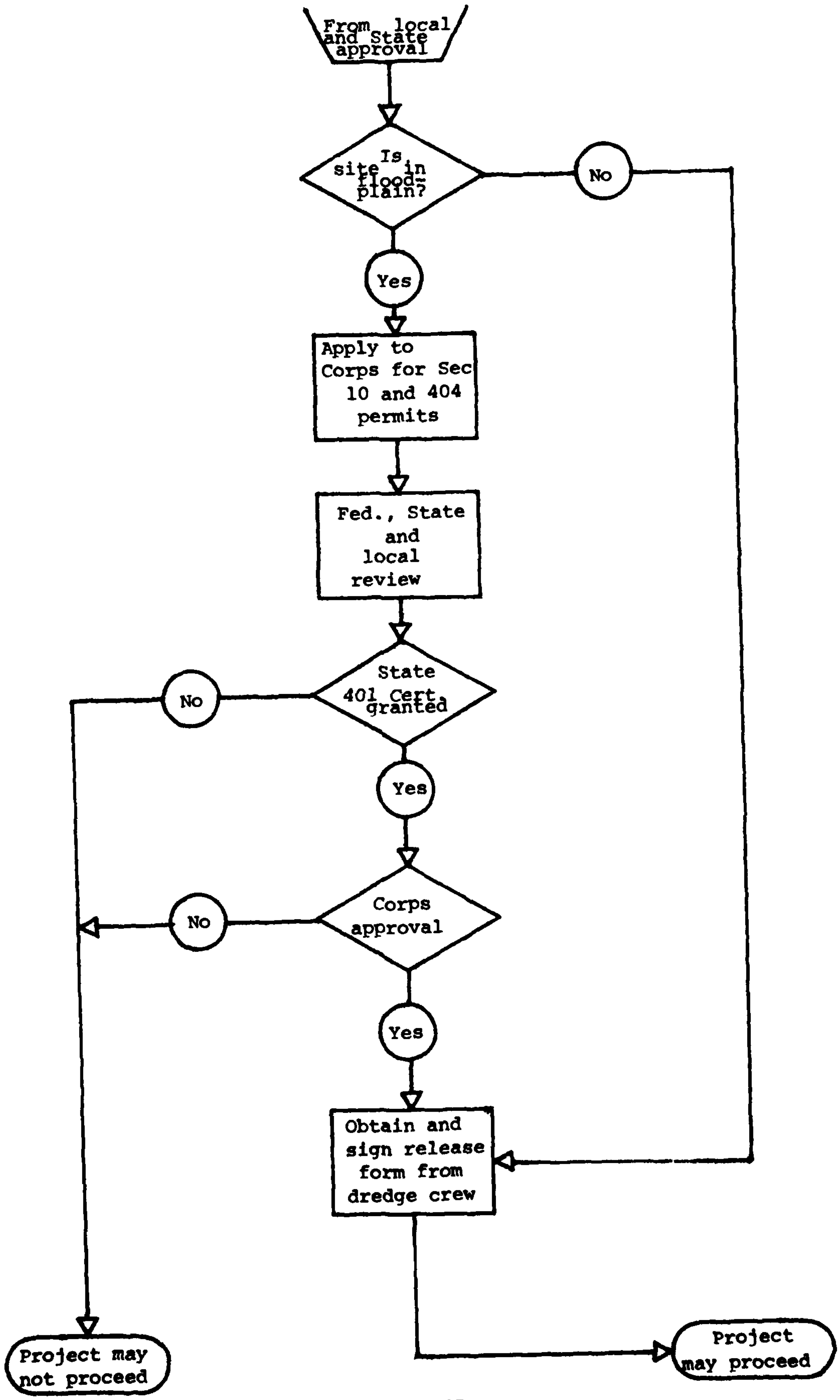


Figure 4. Federal process.



In every case where a landowner is thinking about a development project, he should first check with local and State officials. They will be able to inform him what the restrictions are, if any, and what steps he must take. Permit requirements are not designed to confuse the landowner or take away his rights. Rather, they are designed to ensure that the resources of the region are maintained and that development is carried out giving full consideration to the ability of the land to assimilate it.

The flow charts indicate a three-phase regulatory process with local, State, and Federal phases. Total processing time varies from 2 weeks to 6 months or longer depending on the data available. The process can be speeded up by applying for all necessary permits at the same time. However, a State permit will not be issued without local approval, and a Federal permit will not be issued without State approval.

V. DATA AND RESOURCE INVENTORY

A. GREAT I Base Maps

The FPMWG has had the primary responsibility for providing maps of the river to the GREAT I team. These maps have been used in preliminary work group mapping and the GREAT I final report.

Since early 1975, the work group has been working to produce base maps of the floodplain that would serve the needs of other GREAT I work groups. Aerial photographs of the river were given first consideration for mapping. (See discussion under Floodplain-Floodway Mapping following.) These photo maps have served the needs of the work groups quite well.

During July and August 1975, the FPMWG circulated a questionnaire to work group chairmen to assess their mapping needs. On the basis of the responses, a mapping program was established. In 1976, a corridor map was prepared by the Corps of Engineers at a scale of 1:250,000, outlining the study area. It was designed to provide an overview of river features. Other work group chairmen identified a need for a base map of suitable quality for the final report and work group appendixes. Initial discussions by the FPMWG produced a recommendation for reflying the river and obtaining air photos during low-water, leaf-off conditions. These photos would have served the needs of the team for accurate, readable base maps. However, the elements of topography and elevation would be missing from these photos, and the total cost of the project was seen as prohibitive.

The use of mosaic composites of color separates from U.S. Geological Survey 7 1/2-minute quad sheets was investigated. This technique was used by a contractor conducting the geographic information system pilot project in pools 4 and 5. The Geological Survey in Rolla, Missouri, was contacted to obtain technical assistance in developing a base mapping program using this alternative. A feasibility report and base mapping recommendations were prepared that called for production of mylar positives of 7 1/2-minute quad sheet mosaics

covering pool areas of the river at a scale of 1:24,000 (see Technical appendix D). A contract was awarded to the Geological Survey to produce these maps for GREAT I. There are 19 map sheets that cover the GREAT I study area. The project was completed in August 1978. These maps have become the base for the floodplain and floodway maps produced by the FPMWG.

Since the maps were distributed to the GREAT I member agencies and the general public, there has been a demand for other types of maps. Maps that identify depths and bottom configurations in backwaters are needed. This information would be useful to identify fisheries habitat, determine patterns of sediment and water movement, and extrapolate channel cross sections for input to mathematical modeling (see Sec. VI. B.1.d.).

The GREAT I base maps do not provide detailed topographic information on the floodplain. Supplemental contours are indicated on some maps at 5-foot intervals. However, this interval is not detailed enough to provide resource managers and planners with the information needed for intensive land use, recreation, and wildlife management. Detailed topographic information on islands and bottomlands would also aid in location of dredged material placement sites.

In consideration of the needs expressed above, the FPMWG recommends that detailed topographic and hydrographic maps of the Upper Mississippi River bottomlands in the GREAT I area be produced. The maps should be at a scale no smaller than 1:12,000 (1 inch = 1,000 feet) on an ortho-photo base with a contour interval of 2 feet. The maps should be produced in a format facilitating their use by the general public. Costs of production should be recovered through sales of published maps to the general public.

Implementation Procedure: Congress should appropriate money to the U.S. Geological Survey to accomplish this task.

Rationale: These maps would have several purposes related to management of the Mississippi River bottomlands. The information could be used to define cross-section dimensions for floodplain management math modeling. The alternative to obtaining cross sections from maps

is to conduct field surveys as needed. The maps would also be useful to recreational users of the river, especially fishermen and hunters. Fish and wildlife managers would find the maps useful in quantifying existing habitat and planning for improvements or creation of additional habitat in critical areas. This information base would also serve the needs of State agencies and local units of government in planning, management, and regulatory activities.

There has already been a demand by the public for copies of the GREAT I base maps. It is estimated that partial costs of producing the maps could be offset by selling the published maps to the general public. This approach is used by the Geological Survey in production of topographic quadrangle sheets. An appropriate format for the maps would be one similar to the navigation chart booklets published by the Corps of Engineers.

B. Floodplain-Floodway Mapping

This section describes the efforts the FPMWG has made to address the problem with the highest priority: "Lack of floodway/floodplain mapping."

Basic terms in floodplain management are defined as follows:

Flood. A temporary rise in stream flow or stage that results in inundation of the areas adjacent to the channel.

Floodplain. - The channel and adjacent areas that are inundated by floodwaters.

Regional flood.- A flood of such intensity that it could be statistically predicted to be equaled or exceeded once every 100 years. This flood is also called the 1-percent chance (or 100-year) flood.

100-year or regional floodplain. - The area along a watercourse that would be covered by the 1-percent chance or regional floodwaters.

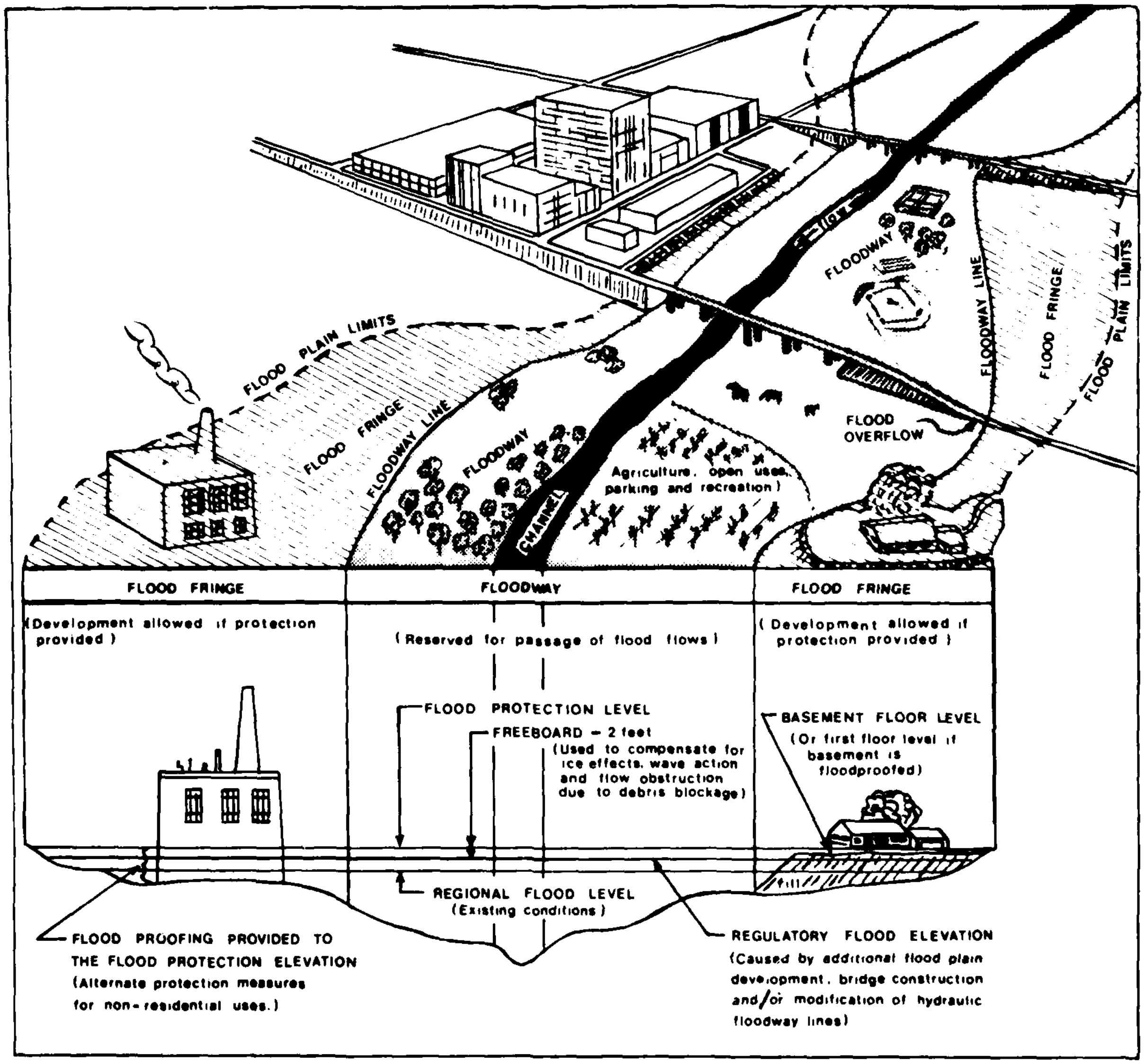
Floodway. - The channel of the watercourse and those portions of the adjoining floodplains which are reasonably required to carry and discharge the regional flood.

Flood fringe. - The portion of the floodplain outside the floodway.

These concepts are illustrated in Figure 5.

Figure 5

Illustration of basic concepts in floodplain management.



Source: Floodplain Regulation Administration Manual, Wisconsin Department of Natural Resources, January 1978.

The science of floodplain management recognizes the efficiency of the floodplain for conducting floodwaters. Floodplain management regulations are designed to protect life and property during floods by guiding development in floodplain areas. Various methods are available to floodplain managers to accomplish this objective.

Floodplain management techniques can be categorized as structural or nonstructural. Structural approaches to floodplain management include:

Levee construction. - In this case, structures which have already been built in areas subject to flooding are protected by building a wall or levee between them and the river. Usually, the levee is constructed around an entire section of a community which is subject to flooding or parallel to the river channel where large areas need protection. Levees are effective against floods for which they are designed. However, if a flood occurs which is higher than the flood designed for, the levee is overtopped and destruction occurs behind the levee.

Levees may have been effective under the prevailing conditions when constructed. However, changes in the watershed upstream can decrease the degree of protection which a levee affords. Levees decrease the storage capacity of the floodplain and constrict the flow of water resulting in higher flows downstream and higher stages upstream during floods.

Reservoir construction. - Reservoirs hold excess runoff from snowmelt or rains in the watersheds of streams and rivers. The water can be gradually released over a longer period of time. Reservoirs are usually emptied during the winter so that their storage capacity is at a maximum during spring runoff. They are expensive to build and often inundate productive land.

Also, sedimentation reduces their effectiveness with time. As with levees, they can be rendered less effective by changes in the basin characteristics over a period of time. Also, they cannot protect from floods that result from excess runoff in the watershed downstream of the reservoir.

Flood proofing. - Flood proofing is applied to structures existing or being built in floodplains. Flood proofing measures are applied to individual structures to protect them from destructive effects of flooding. Usually the lower floors and walls of structures are sealed or the building is elevated on fill above potential floodwaters.

Emergency work. - Often, a community will try to make up for inadequate flood protection by frantically constructing temporary levees and sandbag works at the threat of an approaching flood. These measures are sometimes effective. Often they merely reduce the extent of the damage. Temporary levees of this type are subject to failure and sometimes cannot be built quickly enough. The costs of such efforts are high, especially if they must be repeated every few years. For example, in 1965 the St. Paul District Corps of Engineers spent over $6 million for flood fighting on the Mississippi River.

Nonstructural measures are as follows:

Implementation of floodplain zoning ordinances. - These ordinances restrict floodplain development to those uses which are not readily damaged by floodwaters. Such permitted uses are agriculture, recreation, parking lots, etc. Most ordinances prohibit buildings in the floodway and restrict them to the fringe areas. Floodplain ordinances often meet with opposition from people who resent having controls put on the use of their land. Also, the ordinances are not very effective in protecting existing floodplain development. They are effective, when properly enforced, in guiding the growth of newly developing areas and result in long-term economic benefits by reducing flood damages.

Relocation. - For those areas in the floodplain where potential for flood damage exists and structural measures are not feasible, removal of people and structures from an area may be the only alternative. Relocation is expensive and usually disrupts community social and commercial patterns. If it can be implemented, it works well in protecting life and property from floods.

Most floodplain management programs for communities along the Upper Mississippi River contain both structural and nonstructural measures.

One of the important prerequisites to any type of floodplain management is the identification of the floodplain and floodway limits.

The FPMWG adopted the April 1965 flood as the approximate regional flood in the GREAT I study area. In some reaches of the river, the 1965 flood elevation was higher than the calculated 1-percent chance flood and in other reaches it was lower. For the purposes of the work group, it was decided to map the 1965 high-water limit for the purpose of identifying the floodplain (see conclusion 1).

Photo Base - Floodplain Map. - In 1975, the FPMWG contracted through the Corps of Engineers to obtain aerial photographs of the river from Hastings, Minnesota, to Guttenberg. The floodplain upstream from Hastings had already been mapped. The photos were prepared in a 30- by 30-inch mylar positive format at a scale of 1:9,600 (1 inch = 800 feet) to serve as the base for floodplain mapping. Enlargements of the aerial photographs of the 1965 flood were obtained to define the high-water limit.

A contractor was selected to map the 1965 flood high-water limit onto the base photos. Relevant municipal boundaries and place names were added. Black-line prints of the maps were sent to all the work groups. Because the base photos were not rectified and the floodplain limit lines were not tied into ground control points, the maps cannot be used for legal definition of the floodplain. However, the maps have been useful for general location of floodplain boundaries.

These maps served as draft base maps for several GREAT I work groups. The FPMWG used these maps to define the floodplain while evaluating alternative dredged material placement sites for the channel maintenance plan.

GREAT I Base Map - Floodplain Maps. - The FPMWG decided that the photo base floodplain maps would not be appropriate for the final report. The work group decided to have a contractor map the 1965 flood limit on the GREAT I base maps prepared by the U.S. Geological Survey. The contractor prepared the maps by enlarging the base maps to match the 1965 flood photos. The flood limit was then traced onto overlays to the base maps.

GREAT I Base Map - Floodway Maps. - The first step in floodway mapping is to define the floodway limits on the river. The FPMWG has met several times to determine what the definition of the floodway should be for the purposes of GREAT I floodway mapping.

Along the Mississippi River, the floodway concept has been applied in different ways by different municipalities. Some communities have adopted ordinances in which the floodways were determined by the use of flood photographs. Some municipalities have floodways determined by a computerized step-backwater model, such as HEC-2. Based on the science of river mechanics, the model can define the limit to which the floodplain could be restricted without impeding flood flows.

The FPMWG decided that the floodway should be mapped only in those cases where it has been designated by an approved local ordinance. In any case, it defines the area of the river floodplain in which no development can occur by law. In those cases where no floodway has been adopted by ordinance, there is no floodway mapped. Floodways along other reaches of the river must be determined on a case-by-case basis in accordance with procedures established in local ordinances.

The floodway for the FPMWG floodway maps was drafted by the States in the GREAT I area on overlays to the GREAT I base maps.

Technical Appendix E contains the floodway and floodplain maps prepared by the GREAT I FPMWG. As is noted on the maps, the floodplain is the limit of the 1965 flood. Floodplain and floodway boundaries indicated on the maps are intended to be used for general planning purposes only. The official boundary maps are included as part of local ordinances. These ordinance maps must be consulted for evaluation of detailed site locations. These maps have served to guide the GREAT I Team in preparing final river management planning recommendations and compliance with floodplain management Executive Order 11988.

VI. EVALUATION AND FORMULATION OF DETAILED PLANS

The FPMWG reviewed and evaluated the GREAT I Channel Maintenance Plan to describe its potential impacts on the floodplain. The work group has also developed a suggested framework for the floodplain management component of future comprehensive planning on the river. This section addresses these two items.

A. Channel Maintenance Plan Review

The GREAT I channel maintenance plan consists primarily of proposed dredging and placement sites for each navigation pool of the river. The plan also contains recommendations for the type of dredging equipment to be used for each job. The FPMWG has reviewed this plan primarily to determine what effects the plan would have on the ability of the river to conduct floodwaters.

1. Site Inspection Review

During each of the 4 years of the GREAT I study, the Team has adopted guidelines to direct the dredging and placement activities of the Corps of Engineers. Part of these guidelines has been the formation of an On-Site Inspection Team (OSIT). The OSIT is composed of representatives from each of the GREAT I agencies. Its primary function has been to examine alternative dredged material placement sites and select the sites that best meet the guidelines.

Representatives of the FPMWG attended many of the OSIT meetings on the river. They provided input on the location of the floodplain limits where removal of material from the floodplain was considered.

During the 1978 dredging season, a record was kept of each dredging job to determine the location of the placement site with respect to the floodplain and floodway. The OSIT Habitat Evaluation Form contained a section to indicate whether the placement site for each dredging job was in the floodplain or the floodway (effective flow area). During 1978, all of the placement sites were in the floodplain. Of these, 24 were in the effective flow area and 5 were in the flood fringe.

2. Qualitative Review

In the winter of 1978, the GREAT I Plan Formulation Work Group identified several potential dredged material placement sites as the initial components of the Channel Maintenance Plan. These sites were identified from several sources including the GREAT I Dredged Material Uses Work Group. Each of the sites was selected without regard to any merits other than that it would hold dredged material. Each of the GREAT I work groups was asked to review the potential placement sites from the viewpoint of its own expertise.

The FPMWG developed an evaluation form to guide review of the placement sites. (See Figure 6.)

GREAT I-FLOODPLAIN MANAGEMENT WORK GROUP

DREDGED MATERIAL PLACEMENT SITE

EVALUATION FORM

Page ____ of ____

Pool Numbe ______

Date of Evaluation ______

Sites Evaluated ______

Site Number	LOCATION					PERMIT REQUIREMENTS		EVALUATION OF EFFECTS ON FLOOD FLOWS					RECOMMENDATIONS		
	Out of Floodplain	Flood Fringe	Ord./Des. Floodway	Effective Flow Area	Further Study	Local Ord. Exists	Other Permits Required	No Effect	May Have Effect	Probably Has Effect	Needs Further Study	Analysis needed for Quantitative Evaluation	Approved	Not Approved	Suggested Changes In Placement to Reduce Flood Flow Impacts

Figure 6

The form was designed so that each site could be evaluated on the following factors:

a. Location of the site with respect to the floodplain and floodway.

b. Applicable ordinances or permit requirements.

c. The judgment of the work group as to the probable effects of the site on flood flows.

d. The type of analysis needed for quantitative review.

The form includes spaces for recording whether the site was approved and any modification to make the site more acceptable. The following criteria were applied to determine whether a site should be approved:

a. Use of the site is judged to have no effect on flood flows - <u>approved</u>.

b. Use of the site may have an effect on flood flows - <u>not approved</u>. In some cases where effects were judged to be negligible, the site could be approved, providing the majority of other work groups favor the site. These cases are noted in the "Suggested Changes" column.

c. Use of the site probably has effects on flood flows - <u>not approved</u>.

In all cases where sites are not approved, the work group has made provision for the site to be used. If a quantitative evaluation of the potential effects of a site is made and the analysis shows no raise in flood stages or increase in discharge, the FPMWG will have no objections to use of the site.

In some cases where there is a potential for beneficial use of material from a site, if the material is removed before high water, the site could be approved. These cases are noted on the evaluation forms.

Out of 1,137 total placement sites, the FPMWG granted approval to 321 and did not approve 694. The remaining 122 could be approved subject to meeting certain conditions.

The complete series of evaluation forms is in Technical Appendix F. The first page of the appendix explains the symbols used on the forms.

The information provided by the FPMWG was submitted to the Plan Formulation Work Group to be used in selection of placement sites for the GREAT I Channel Maintenance Plan. In providing further guidance to the Plan Formulation Work Group, the FPMWG developed recommendations reflecting the work group position on placement of dredged material (see section VIII). The review of potential placement sites also led to recommendations concerning acquisition of placement sites and methods for removal of dredged material from floodplain areas. These recommendations are also included in Section VIII.

3. Quantitative Review

The FPMWG would have liked to have been able to calculate the potential effects on flood stages of each placement site. Unfortunately, the money needed for such an effort was not available through GREAT I funds. A quantitative analysis usually implies the application of some type of mathematical model. These models are designed to evaluate changes in water surface elevations or flows resulting from modifications to river channel cross sections. To provide rapid calculation of the equations, the models are usually computerized.

The types of models vary. Some models can only calculate the change in water surface elevation resulting from encroachments (filling in the floodplain). More sophisticated and complex models are designed to determine the effects on river storage resulting from encroachments and loss of backwater storage capacity. From this basic classification, floodplain management models can be broken down further into subfunctions. Some models assume that a river bed does not change with flow, while others consider sediment transport in a stream bed as part of the calculations. Some models assume that flow does not change with time, while others can account for this change. Some hydraulic models are able to consider flow in two dimensions - both downstream and laterally.

The FPMWG considered applying the normal depth calculation to make a rough quantitative analysis of individual placement sites. This approach was not acceptable to the work group. The reason for rejecting this approach was that the main concern in evaluating flood flow impacts of dredged material placement is an assessment of cumulative effects. The normal depth equation is designed to calculate the effects at one cross section. The FPMWG is concerned with the cumulative effects of 50 or more years of placement at several locations within each pool. The only type of analytical tool for assessing multiple cumulative effects on flood stages is a hydrologic/hydraulic model.

In evaluating the potential placement sites for the channel maintenance plan, the FPMWG has indicated for each site what type of mathematical model would be needed to quantitatively evaluate impacts on flood flows. The work group assumed that the model would be one-dimensional and unsteady state. In running a model to determine impacts of placement sites, all placement sites within a significant hydraulic reach (usually a complete pool) must be included. It is not appropriate to run the model to assess the impacts of a single site.

The following section describes the work of the FPMWG regarding mathematical models for floodplain management. The work group has identified a need for a mathematical modeling program to evaluate the long-term cumulative effects of in-floodplain dredged material placement.

B. Other Management Plans

Besides the channel maintenance plan, the GREAT I final report contains recommendations and a framework for comprehensive resource management planning on the Upper Mississippi River. This framework considers channel maintenance as an important component but also includes recreation, fish and wildlife, commercial navigation, and other uses of the river. The FPMWG has approached this aspect of the GREAT I Study by investigating needs for broad, comprehensive floodplain management and making recommendations to meet those needs.

1. Application of Mathemetical Models

a. Need for a Model

As explained in Section VI.A.3., the FPMWG was not able to conduct a detailed quantitative analysis of potential dredged material placement sites. The quantitative review of sites gives some indication of their effects on flood flows, but in no way describes the magnitude of the effects. According to the requirements of Presidential Executive Order 11988, the magnitude of the effects must be calculated before the sites can be used.

Placement of dredged material in the floodplain can affect flood flows in two ways. If backwaters that normally store floodwaters are filled in or blocked off by dredged material, the amount of flow, or discharge, at downstream locations during floods could increase. This increase in discharge during peak flow could have serious consequences downstream where the floodplain must handle the increased rate of flood flow. Secondly, if dredged material is placed in the path of moving floodwaters, it can cause water to back up and flow at a higher elevation in areas adjacent to or upstream of the material. If levees or flood proofing measures are overtopped as a result, the consequences could be disastrous.

GREAT I has proposed to locate some dredged material in the Upper Mississippi River floodplain during the next 50 years. The effects of such placement must be quantified.

Some of the actions recommended by the other work groups could affect flood flows. These actions are described in detail in Section VII. The potential effects of some of these actions must be quantified.

The FPMWG recognized the need for some type of math model for floodplain management. However, the work group decided to consult other sources to determine which model would be most appropriate.

b. Coordination with UMRBC Technical Task Force

In May 1977, the Upper Mississippi River Basin Commission organized a Floodplain Management Technical Task Force. The main function of the task force was to guide the Corps of Engineers in its revision of flood frequency-discharge values for the river. The task force included representatives of the Corps of Engineers; the Soil Conservation Service; the U.S. Geological Survey; the Federal Insurance Administration; and the States of Minnesota, Wisconsin, Iowa, Illinois, and Missouri.

In April 1977, FPMWG sent a letter to the chairman of the task force asking for technical assistance in selecting a model. The FPMWG had concluded that the task force represented the best source of expertise on floodplain management available (see conclusion 4). The Task force was presented with the specific needs of the FPMWG.

In November 1977, the task force responded with this statement:

> "If models are applied to determine the effects of dredged material disposal along the Upper Mississippi River Main Stem, it is the recommendation of the FPM Technical Task Force that the HEC-1 model with the modified PULS routine be used to evaluate the effects of valley storage and that the HEC-6 model be used to evaluate the effects of floodplain restrictions."

c. Math Model Pilot Study

The FPMWG decided, based on the Technical Task Force recommendations, that a mathematical model should be applied to an actual situation on the Mississippi River. On the basis of the results of this pilot study, a recommendation could be made for wide-scale modeling of the river.

The FPMWG decided to apply a math model to the area of pool 4 between the lower end of Lake Pepin (RM 765) and lock and dam 4 at Alma, Wisconsin (RM 753). The reasons for selecting this reach were that:

(1) Extensive cross-section, flow, and sediment data were already available.

(2) The area received heavy amounts of dredging and placement.

(3) The area was being modeled with a two-dimensional computer model and a physical model by other GREAT I work groups.

The next task for the work group was to select which type of model should be applied in the pilot study. The work group decided that the model to be applied should be one-dimensional, unsteady state, and able to account for loss of floodplain storage. Two such models were the UMRBC task force recommendation (HEC-6/HEC-1) and a one-dimensional model developed by the Engineering Research Center at Colorado State University. Both models had comparable advantages. The disadvantages of the HEC-6/HEC-1 combination were the amount of manual fine tuning required before results could be obtained. Therefore, the HEC-6/HEC-1 combination was rejected.

A one-dimensional model available through Owen Ayres and Associates, a private engineering firm, was judged by the work group to be comparable to Colorado State University's model. Proposals for the pilot study were requested from Colorado State University and Owen Ayres and Associates. The Owen Ayres proposal was accepted, and a contract was awarded in the

summer of 1978. Model development was subcontracted to Gingery Associates, Inc., in Denver, Colorado. The model developed for this project is called the Compound Stream Flow Model. It is one-dimensional and unsteady-state.

The FPMWG decided that the pilot study should be set up to test the Compound Stream Flow Model's ability to predict the river's response to loss of floodplain storage and encroachment on the floodway. Two placement schemes were proposed by the work group for testing in the model. Placement sites identified for analysis in the Compound Stream Flow Model were hypothetical and designed to produce a flood profile increase resulting from loss of storage and/or equal degree of encroachment only for the purpose of testing the predictive ability of the model. These placement sites have not been, nor will they be, recommended for use by GREAT I or the Team participants. (See Technical Appendix G for copy of final report on this study.)

The contractor completed work on this project in May 1979. The model projected an increase in flood stages from floodway encroachment and loss of floodplain storage.

A significant finding was that, for the reach of river modeled, 10 to 50 percent of the flow during the 1965 flood was in the overbank or backwater areas. Other recent model studies in this reach have based investigations on the assumption that 95 percent of the effective flow was confined to the main channel and immediate overbank. The results of the Compound Stream Flow Model, which accounted for flow over the entire floodplain, would indicate that this assumption is not true for some reaches (see figure 7).

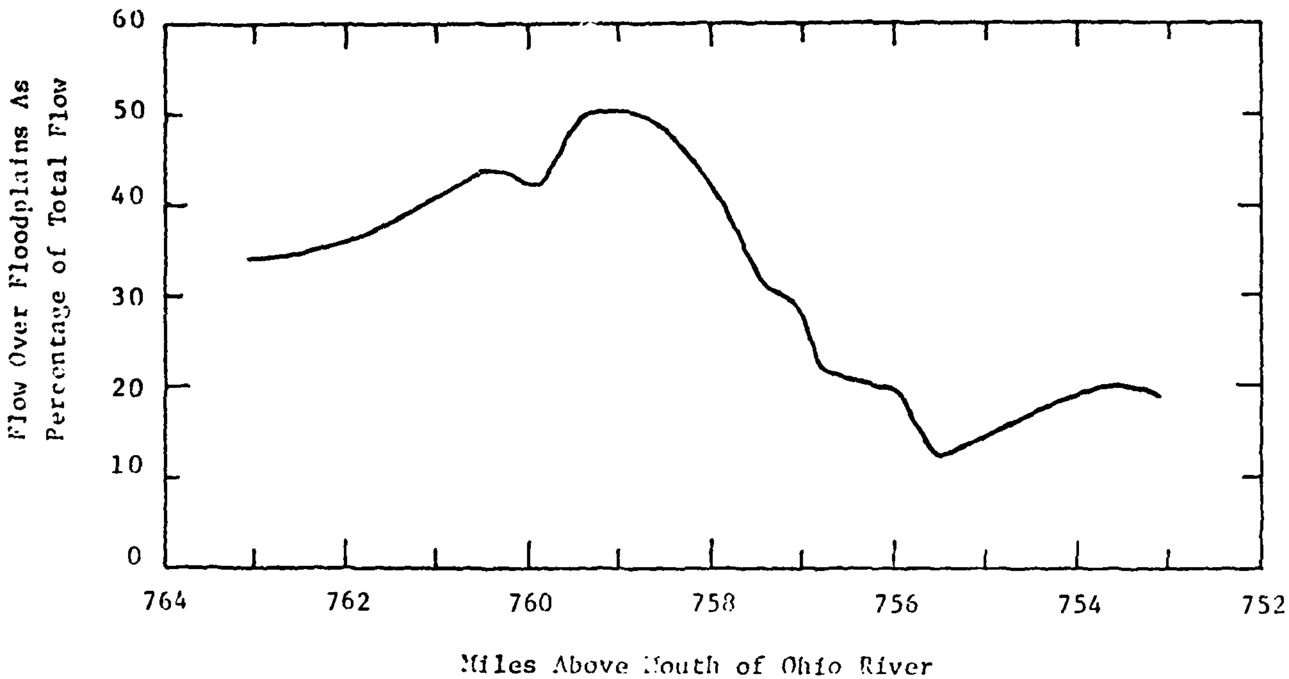


Figure 7. Flow over the floodplains shown as percentage of the total flow for the 1965 flood (average discharge 267,000 cfs) in Pool 4 of the Upper Mississippi River

Source: Compound Stream Flow Model for Pool 4 Reach of the Upper Mississippi River, April 1979.

On the basis of the project results, the FPMWG concluded that the Compound Stream Flow Model, as applied to this particular project, has analytical and predictive capability for floodplain management. Consequently, the FPMWG has based a recommendation on math modeling or this conclusion.

d. Recommendation and Data Needs

The FPMWG offers the following recommendations regarding math modeling for floodplain management on the Upper Mississippi River. These recommendations are designed to address work group problem 3 - need to determine effects of navigation project operation and maintenance on flood stages.

Recommendation: The FPMWG recommends that a computerized, hydrologic/hydraulic math model be developed to evaluate the impacts of long-term dredged material placement or other encroachment on the flood-carrying capacity of the Upper Mississippi River 9-foot channel project. The FPMWG supports the feasibility study for and ultimate development of math modeling for floodplain management proposed by the UMRBC Floodplain Management Technical Task Force and supports efforts by the UMRBC to obtain funding for this project. On the basis of investigations conducted by the FPMWG, the Compound Stream Flow Model (see Technical Appendix G) has been found to be suitable for this purpose and should be investigated as part of the feasibility study.

Implementation Procedure: Congress should provide funds through the UMRBC for the feasibility study and through the Corps of Engineers to develop the model. The Corps of Engineers, in consultation with State floodplain management agencies, the Federal Emergency Management Agency, and the U.S. Geological Survey, will be the implementing agency for model development and application.

Rationale: The model could be used to evaluate the impacts of long-term dredged material placement or other encroachment on the flood-carrying capacity of the river.

A math model of the river for floodplain management purposes will solve the following problems in the Mississippi River floodplain:

- Lack of knowledge of effects of long-term (50-year) placement of dredged material in the floodplain.

- Lack of definition of the hydraulic floodway and encroachment limits for most reaches of the river.

- Lack of knowledge of flood elevations between gaging stations.

- Time and expense involved in case-by-case review and evaluation of individual proposed development projects.

- Inability of local municipalities to provide the necessary resources to deal with floodplain management problems.

- Frequent challenges to decisions to restrict floodplain development which are made without adequate objective data.

(Source: "Recommendations and Supporting Information for a feasibility study on Math Modeling of the Mississippi River for Floodplain Management Purposes," unpublished draft, Upper Mississippi River Basin Commission, June 1978.)

The following statements from other sources are offered in support of this recommendation.

From the UMRBC Floodplain Management Technical Task Force:

> "It is the recommendation of the Technical Floodplain Management Task Force of the Upper Mississippi River Basin Commission that a study be authorized under the authority of the Upper Mississippi River Basin Commission to determine the feasibility of developing a computerized math model or models capable of providing information for floodplain management purposes in the Mississippi River system."

From Main Stem Level B Study draft recommendations:

A variety of structural and nonstructural measures have been implemented to mitigate flood damages. State and Federal agencies should develop an appropriate mathematical model of the total main stem hydraulic and hydrologic system that would provide a sound data base for future land use management.

Several mathematical models have been developed that would be appropriate for use on the Upper Mississippi River. The UMRBC Floodplain Management Technical Task Force has prepared a list and description of the various models. (UMRBC, June 1978.)

The FPMWG considered the various options available in recommending a specific model. The favorable results obtained from the math model pilot study indicated that the Compound Stream Flow Model has several advantages over the other models considered. The Compound Stream Flow Model is unsteady state and can account for changes in floodplain storage and sediment transport. The HEC-2 model, most commonly used for floodplain management analysis, is steady state and does not include sediment transport. A combination of HEC-6/HEC-1 requires considerable trial-and-error fine tuning to coordinate the sediment transport, backwater effects, and routing functions. The one-dimensional sediment transport model developed for GREAT I by Colorado State University does not account for flow over the entire floodplain.

The development of such a model must be consistent with the findings of the feasibility study proposed by the UMRBC Floodplain Management Technical Task Force if such a study is conducted. "The development and use of a math model(s) of the Mississippi River would provide a systems approach to the Management of the River, providing a sound and consistent analytical tool for use by Federal, State, and local agencies as well as private developers." (UMRBC, June 1978.)

Data Needs: The major data need for development of a mathematical model is valley cross sections. The GREAT I Dredging Requirements Work Group has collected cross sections for use in a one-dimensional sediment transport model. However, these cross sections do not cover the entire floodplain. Following are guidelines to be used in selection and design of cross sections:

(1) It is desirable for the agency or consultant to jointly select with the contracting agency the location where cross-sectional survey data are to be acquired before initiation of the study.

(2) Where possible, the lateral extent of the survey line will be shown on both sides of the river or directions will be given as to the vertical distance above the water surface that the surveys must be made. Extreme care should be taken to ensure that the lateral survey limits cover all the area that could be inundated by regional (100-year) floodwaters.

(3) Alignment on map/photo will correspond to the direction that the cross sections are to be made.

(4) Cross sections should be located approximately at right angles to the direction of flood flow.

(5) Cross sections should represent or be typical of the area between two consecutive sections.

(6) Cross sections should be located:

(a) Where changes in cross-sectional area occur.

(b) Where retardance to flood flow changes.

(c) Where changes in slope occur.

(d) At man-made or natural restrictions or encroachments.

(e) At regular intervals along reaches where none of the above occur.

(7) For bridges, culverts, and road crossings, cross sections should be located:

(a) 50 feet downstream and 50 feet upstream of the crossing and parallel to it.

(b) Under the crossing structure.

(8) The survey chief should exercise judgment in acquiring the survey data. Where site distances would be considerably improved by slightly shifting the survey line, such practice is encouraged to reduce survey costs. Whenever the location or alignment of the survey line is changed, it should be indicated on the map/photo and submitted with the survey data.

(9) In the field, the location to be surveyed can be determined by visual observation through references to identifiable points on the map or aerial photograph.

(10) The elevation of ground points should be determined along the survey line at all major breaks in ground slope and at reasonable intervals based on the length of survey line.

(11) Survey sections should be tied into mean sea level datum using the nearest bench mark. Ordinary leveling accuracy should be adhered to. Usually stadia accuracy is adequate for location of points along the survey line.

(12) Survey information should be plotted so that it may be interpolated to the nearest 0.1 foot vertically and to the nearest foot horizontally. For very long survey lines, such as 1,000 feet or more, a smaller horizontal scale may be practical.

(13) It is important to properly tie the data acquired from detailed topographic maps to the surveyed channel data. The channel information obtained in the field should include a point at least 50 feet on each side of the channel.

(14) Where detailed topographic maps are available, the overbank portion of the cross section can usually be obtained by scaling the distances to the contour lines on a topographic map. If the percentage of flow carried by the channel is small compared to the percentage of flow carried by the overbanks, a hand level may be used to obtain the channel portion of the cross section.

As an alternative to collecting new cross sections, the existing partial cross sections may be extended by extrapolating the data from preimpoundment topographic surveys taken by the Corps of Engineers in the late 1920's and early 1930's. In cases where backwater areas are known to have been disturbed, the continuous survey data would not be appropriate.

Costs: The cost of the math model feasibility study has been estimated at $100,000. Other costs associated with data collection and model development are necessarily related to the recommendation of the feasibility study. Estimated costs range from a low of $2,000,000 to a high of $10,000,000. However, these costs have been estimated without the benefit of a feasibility study or knowledge of the capabilities of the Compound Stream Flow Model. Costs for model development alone could be as low as $500,000 for the 850 miles of the Upper Mississippi River or $200,000 for the GREAT I portion of the river. Data acquisition costs are difficult to estimate; the following is a general estimate. These figures are preliminary and subject to revision as new data become available.

Table 2 - Data acquisition costs

Item	Amount
GREAT I area	
Supplement to existing partial cross sections (using continuous topo survey data)	$360,000
One additional cross section per mile	1,200,000
Total	1,560,000
Mississippi River from the Ohio River to the Twin Cities	
Total for GREAT I reach	1,560,000
New cross sections - RM 0 to 610	1,500,000
Total	3,060,000

The model must be used to analyze cumulative effects of floodplain encroachments pool-by-pool. All encroachments affecting a pool must be analyzed for their cumulative effects on flood flows in that pool. Separate case-by-case analyses will not predict the actual effects. Such fragmented analyses can be misleading. For example, a separate analysis for each dredged material placement site in a pool will show relatively minor effects. However, when all placement sites are analyzed together, the true effects are revealed. To insure that cumulative effects are analyzed by the model, the work group developed a recommendation concerning model application.

Recommendation: Projects in the Mississippi River 9-foot channel floodplain that involve an encroachment or loss of storage should be entered in the mathematical model to keep the data base current and ensure that cumulative effects of floodplain development are evaluated.

Implementation Procedure: Federal, State, and local agencies should adopt procedures to ensure that all floodplain development is accurately recorded and the data sent to the Corps for inclusion in the math model. This procedure should be accomplished by providing copies of issued permits for fill or development to the Corps of Engineers.

Rationale: To ensure that the cumulative effects of floodplain development on flood elevations are recorded, public regulatory agencies must forward development information to the Corps of Engineers. Any runs of the model made without including added development will not accurately reflect river conditions during floods.

2. Floodplain Management Coordination

a. Needs

The FPMWG has identified a need for coordination of floodplain management on the Upper Mississippi River in the GREAT I study area. Floodplain encroachment limits are not consistent between States. Presently, no method allows opposite bank effects to be evaluated in issuance of a local floodplain zoning permit.

In addressing this issue, the FPMWG has explored alternative methods of meeting the need for uniform standards. One approach that was explored was to develop a memorandum of understanding between the States. In adopting that document, the States would agree to apply one standard for allowable encroachment stage increases to projects along the river. However, Wisconsin legal staff indicated that such a memorandum of understanding could not, under Wisconsin law, be used to require Wisconsin counties and municipalities to enforce standards adopted by another State unless those standards were also adopted by the Wisconsin DNR to apply statewide in similar situations.

There are several problems involved in adopting standard encroachment limits. One problem is that, depending on the standard chosen, at least two, and maybe all three, States would apply different standards to landowners along the river than those applied to people in the rest of the State. Another problem is that Minnesota and Iowa rules and regulations allow for administrative flexibility in application of encroachment limits, but Wisconsin rules require special flooding easements to be acquired by the project sponsor to deviate from the established standard. Therefore, if an agreed upon standard is less restrictive than the Wisconsin requirement, either the sponsor would bear the burden of the interstate agreement, or else Wisconsin would have to change its rules. Another problem is that each existing local floodplain zoning ordinance would have to be modified to reflect changes required in an interstate agreement. While these problems are not insurmountable, they do explain why the FPMWG has had difficulty in resolving this issue.

Nevertheless, there is a very real need expressed by the general public and others for consistency in application of floodplain management standards along the river. There is clearly a need for ongoing effort in this direction.

b. Recommendation

The following recommendation is designed to partially address work group problem 2 - lack of interstate consistency in definition of floodway.

Uniform standards for floodplain management should be developed for States and municipalities along the GREAT I portion of the Mississippi River. Changes in enabling legislation may be necessary.

Implementation Procedure: The State agencies of Minnesota, Wisconsin, and Iowa that have responsibility for floodplain management are responsible for implementation of this recommendation.

Rationale: At the present time, allowable floodplain encroachment limits are different in each of the three States. However, the effects on water stages of administration of standards on one side of the river are the same on both sides of the river. No framework exists for resolving inconsistencies in standards other than through the courts. Effective floodplain management cannot be applied by the municipalities if standards for encroachment are not uniform across the floodplain.

The FPMWG has addressed this issue and recognizes the need for consistency in application of standards on both sides of the river. Following are statements offered in support of this recommendation:

From the National Forum on the Future of the Floodplain, September 1975:

> "The workshop strongly recommends the adoption of a policy that will encourage multi-agency efforts that can bring to bear appropriate sources of funding and expertise to accomplish objectives not obtainable by single agencies."

From Upper Mississippi River Comprehensive Basin Study vol. V, Appendix I:

> "Establish a flood control organization to administer State floodway - encroachment and dam safety provisions, coordinate flood damage reduction activities with the Federal and local government, and assist in the procurement of needed flood data for the enactment of local ordinances."

VII. PLAN REVIEW

The FPMWG has reviewed the recommendations of the other work groups. The review was based on applying the FPMWG criteria of compliance with State floodplain management standards to the recommended actions. The detailed responses of the FPMWG to each recommendation of other work groups is included elsewhere in the GREAT I Final Report. This section of the final FPMWG Appendix describes the evaluation of selected work group proposals.

A. Fish and Wildlife Work Group

The Fish and Wildlife Work Group (FWWG) recommended the rehabilitation of the backwater habitat in the Weaver Bottoms area of pool 5. The FWWG Appendix discusses the specific features of this recommendation in more detail. Selected side channel inlets in the natural levee along the Minnesota side of the main channel would be closed. The closures would prevent sand from entering the backwater lake area and hindering growth of aquatic vegetation. In addition, the plan calls for building islands in the open water area of the Weaver Bottoms to block wave action and help reestablish aquatic plants.

The FPMWG was concerned with the potential impacts on flood stages resulting from filling in open water and redirecting backwater flow. Consequently, the FPMWG recommended that the FWWG obtain a hydraulic analysis of the project to show any stage increases that might result.

The FWWG obtained the services of the Engineering Research Center at Colorado State University for the analysis. The second run of the computer model analysis indicated that the side channel closure project could cause flood stage increases of up to 0.6 foot. The effects of the windbreak islands on flood stages were not calculated. The 0.6-foot increase is 0.5 foot greater than Wisconsin standards and 0.1 foot greater than Minnesota statewide standards.

The FPMWG requested that the project be designed in such a way that no stage increases result. A permit will have to be obtained from the MDNR before either phase of the project can be constructed. Also, the WDNR has requested that the FWWG conduct additional studies to determine effects of the islands before project construction. Flooding easements must be obtained from all Wisconsin landowners whose lands would be affected by the increases.

B. Recreation Work Group

The Recreation Work Group (RWG) proposed numerous projects that involve placement of dredged material in the floodplain. These projects can generally be divided into two categories.

One category is those projects where dredged material would be placed on islands along the main channel to enhance their use by recreationists. These sand areas are used by boaters during the summer for camping, swimming beaches, picnicking, or just stopping places along the way. The RWG has identified several of these sites where small quantities of dredged material would be placed along the shore.

The other type of project involves creation of new islands or beaches adjacent to existing riverbanks. These islands would be located in the main channel or in the border area of the channel. They would be designed to serve as a location for boaters to beach their craft while waiting to lock through. Some of these lockage waiting areas would require several thousand cubic yards of dredged material for their construction.

The FPMWG has adopted a single approach to the review of these two types of projects. The FPMWG would have no objection to the construction of these projects if it can be shown by appropriate quantitative analysis that the cumulative effect of these projects, in combination with placement sites recommended in the channel maintenance plan, would not affect flood stages.

C. Sediment and Erosion Work Group

The Sediment and Erosion Work Group (SEWG) has identified sedimentation problems on the Upper Mississippi River. Sediments carried into the main stem of the river from tributaries often settle out in the main channel, side channels, and backwaters. The SEWG was concerned about the possible effects of unchecked sedimentation on the flood-carrying capacity of the river. In consultation with the SEWG, the FPMWG identified the need to determine the effects of sediment aggradation on flood stages (problem 5). Both wash load (fines) and bed material load (coarse) sediments can cause sedimentation problems on the river.

1. Wash Load Sediment Effects

Wash load sediments originate in the upland cultivated areas of the watershed. Fertile topsoils are washed into creeks and streams during rainstorms and spring snowmelt and eventually reach the Mississippi River through its many tributaries. After they reach the main stem, most of these sediments, usually silts and clays, are carried in suspension by the current and eventually find their way to the Gulf of Mexico. However, some sediment-laden water is diverted through side channels into quiet backwaters. Here, where the current drops off completely, the silt and clay particles gradually settle to the bottom. In backwater areas that have effective flow during high flows, wash load sediments will not be deposited but will be carried through. This finding has been corroborated by Simons and Chen in a study of sediment flow through the Weaver Bottoms (Simons and Chen, 1977).

The SEWG has done some studies to determine the rate of wash load sedimentation in the backwaters. Based on these investigations, the SEWG determined that backwater areas will eventually become dry land after many years of wash load sediment aggradation. The SEWG asked the FPMWG if the loss of backwater areas to wash load sediments would reduce the capacity of the floodplain to store floodwaters and result in higher downstream flood stages and increased flood damages.

In addressing this concern, the FPMWG based its conclusions on two factors. First, the rate of wash load sediment aggradation above the low control pool water elevation is very slight. Most wash load sediments settle out of the water column only when the water velocity has reached zero. Water velocity in the backwaters reaches zero in most areas when the water elevation is at, or slightly above, low control pool. If the river is above low control pool, the water velocities in the backwaters keep the wash load sediments moving through the system rather than allowing them to drop out. Consequently, the wash load sediments do not build up appreciably above low control pool. The second factor is that the flood storage capacity of the river is in the area of the floodplain above low control pool. Since wash load sediments do not build up to take up the flood storage areas, there will be no appreciable impact on flood elevations from loss of storage. These conclusions are based on a planning time frame consistent with that of the GREAT I Study. Over very long periods of time, sediment buildup could affect flood storage capacity. However, any attempt to quantify that effect would be speculative.

2. Bed Material Load Effects

Coarse sediment enters the Mississippi River as the bed load of tributary streams. This bed material load is generally fine to medium sand that is too heavy to be held in suspension by streamflow. The sand originates from the erosion of sand terraces and banks along the tributaries. The Chippewa River is an example of a stream which contributes a large amount of sand to the Mississippi River.

The sand is usually confined to the main channel and adjacent side channels where the current is fast enough to keep the sand moving. It is this sand that accumulates in the main channel and must be dredged to provide passage for commercial vessels. The sand is also carried into backwater areas during periods of high water and settles out where the velocity slows.

The FPMWG recognizes that aggradation of bed material load can affect flood flows. Probably the most significant impact results from placement of dredged sand in the effective flow or backwater storage areas of the floodplain. Significant accumulations of this dredged material can cause encroachment on flood flows or loss of backwater storage, resulting in higher flood stages. Over a long period of time, if dredging and placement practices do not change, the effects of this aggradation can cause flood damage in population areas.

The bed material load that is carried into the backwaters during high flows can aggrade above normal pool elevation. Over a long period of time, and depending on flow conditions, floodplain storage areas could be lost to sand aggradation.

The FPMWG also recognizes the adverse impacts of both wash load and bed material load aggradation on the river's fish and wildlife habitat. However, these impacts are being addressed by other work groups.

3. Summary of Conclusions

The above discussion yields the following conclusions:

a. Wash load sediment (silts, clay, and organics) aggradation in the Mississippi River backwaters will not significantly affect flood storage or flood stages during the planning time frame of GREAT I.

b. Bed material load (sand) aggradation in the main channel and backwaters is likely to have an increasingly significant adverse impact on flood storage and flood flows during the planning time frame of GREAT I.

c. The FPMWG supports the efforts of the SEWG to reduce the amount of bed material load entering the Mississippi River from tributaries. The flood carrying capacity of the river would be maintained, and potentially destructive increases in flood stages would be avoided.

This conclusion addresses work group problem 5 - need to determine effects of sediment aggradation on flood stages.

The FPMWG has investigated the quantification of the impacts on flood stages resulting from aggradation or deposition of dredged or fill material in the floodplain. (See Sections VI.A.3. and VI.B.1.)

D. Public Participation and Information Work Group

The Public Participation and Information Work Group (PPIWG) through its August 1978 position paper directed two recommendations to the FPMWG that could have significant impacts on the flood-carrying capacity of the river. These recommendations are:

- That the FPMWG support efforts by the SEWG to promote accelerated streambank and upland erosion control practices as a means of reducing sediment flow into the river, thus maintaining the river's flood-carrying capacity.

- That this work group should support a reevaluation of tributary straightening projects and redesign some of the projects where straightening has resulted in major environmental problems.

The FPMWG addressed both these recommendations. On the basis of the evaluations, additional FPMWG recommendations were developed.

The first PPIWG recommendation was discussed by the work group in light of the preceding section. As a result of this discussion, the section was modified to reflect the support of the FPMWG for efforts to control accelerated streambank erosion. The FPMWG has concluded that fine sediment contribution to the Mississippi River backwaters would have a minimal impact, if any, on flood elevations. The work group does recognize the value of some upland control measures in reducing peak discharge on tributaries. Reduced tributary peak discharges can reduce bed load sediment transport and streambank erosion. As noted in conclusions b. and c. of section C.3., above, reduction of bed material load helps maintain the flood-carrying capacity of the river.

Consideration of the first PPIWG recommendation yielded the following FPMWG recommendation:

The FPMWG recommends that streambank erosion control measures be implemented to reduce bed load sediment entering the Mississippi River from the Chippewa and Wisconsin Rivers, Wisconsin; Zumbro and Root Rivers, Minnesota; and Upper Iowa River, Iowa.

Implementation Procedure: The U.S. Department of Agriculture, Soil Conservation Service, should be the lead agency, coordinating with the Corps of Engineers.

Rationale: This recommendation is based on FPMWG conclusion 5 regarding the effects of tributary sediment contributions on the flood-carrying capacity of the Mississippi River. The intent of this recommendation is to lend the support of the FPMWG to the recommendations of the SEWG regarding streambank erosion control. Reduction in bed load sediment entering the main stem from tributaries will reduce dredging requirements in the navigation channel. Reduced dredging volumes will result in less material placed in the floodplain.

Regarding the second PPIWG recommendation, the work group recognized the potential for adverse floodplain management impacts of channel straightening projects. The FPMWG concluded that it would be very difficult to determine the contribution of specific straightening projects to flood stage increases. The FPMWG does not have enough specific information to recommend reevaluation of existing projects. However, the work group agrees that future projects should be evaluated in terms of potential impacts on downstream flood stages. The work group also recognizes the increased sediment carrying capability of channelized streams. Because this sediment is carried into the main channel and requires dredging, the placement of the dredged sediment can affect flood flows. Tributary channelization projects should also be evaluated in terms of contribution to increased sedimentation in the main stem.

As a result of this evaluation, the FPMWG recommends that stream channelization or tributary straightening projects that are proposed for tributaries of the Mississippi River in the GREAT I area be evaluated to determine:

1. Potential increases in tributary discharges during floods resulting from the project.

2. Potential increases in the bed load sediment transport capability of the tributary stream resulting from the project.

Implementation Procedure: The Soil Conservation Service and Corps of Engineers should change their policies concerning planning of stream channelization projects by adding a provision to their environmental impact statement preparation guidelines incorporating the provisions of this recommendation.

Rationale: The FPMWG concluded that stream channelization projects that result in increased tributary discharges could adversely affect flood flows on the main stem by increasing the hydrograph peak of slope of the hydrograph. Increased bed load transport capability of tributaries could result in greater dredging requirements in the navigation channel which, in turn, would result in increased amounts of dredged material placed in the floodplain. These potential impacts must be weighed as costs of construction in planning these projects.

VIII. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been reached by the FPMWG;

1. The 1965 flood was accepted as the approximate regional flood for base mapping purposes.

2. The costs involved in producing topographic maps of the study area from recent air photos are beyond the budget limitations of GREAT I. See recommendation 3.

3. Any mathematical model used to determine river hydraulics with respect to flood flows should be an unsteady state model, incorporating the effects of floodplain storage.

4. Technical guidance will be sought from the Flood Plain Management Task Force of the UMRBC. This task force has representatives from five States - Minnesota, Wisconsin, Iowa, Illinois, and Missouri - and three Federal agencies.

5. Concerning effects of sedimentation on flood flows:

a. Wash load sediment (silts, clay, and organics) aggradation in the Mississippi River backwaters will not significantly affect flood storage or flood stages during the planning time frame of GREAT I.

b. Bed material load (sand) aggradation in the main channel and backwaters is likely to have an increasingly significant adverse impact on flood storage and flood flows during the planning time frame of GREAT I.

c. The FPMWG supports the efforts of the SEWG to reduce the amount of bed material load entering the Mississippi River from tributaries. The flood-carrying capacity of the river would be maintained and potentially destructive increases in flood stages would be avoided.

6. The Compound Stream Flow Model, as applied in a pilot study in pool 4, can be used as an analytical and predictive tool for floodplain management.

Recommendations. - The following recommendations relate to the GREAT I channel maintenance plan and are based on work group objectives, review of potential placement sites, and conclusions reached by the work group.

1. The FPMWG recommends that, for every dredging cut in the GREAT I area, an out-of-floodplain placement site be identified and evaluated for comparison with other alternative sites.

Implementation Procedure: This task must be accomplished by the Plan Formulation Work Group during development of the channel maintenance plan.

Rationale: Presidential Executive Order 11988 on floodplain management requires that for every Federal action proposed to take place in the floodplain of a stream or river, an alternative must be considered that is out of the floodplain. In addition, in-floodplain actions must be evaluated to determine their impacts on the flood-carrying capacity of the watercourse. This recommendation is based on conclusions reached in Section IV. B. on Executive Order 11988.

2. Regarding selection of dredged material placement sites, the FPMWG recommends:

a. In every case where in-floodplain placement of dredged material is proposed, a quantitative analysis of the effects on the 1-percent chance flood be made. The analysis must include a computation of the effect of any encroachment into the floodway by assuming an equal degree of hydraulic encroachment on the other side of the river for a significant hydraulic reach. If the evaluation shows that hydraulic and hydrologic effects are within the limits of applicable State standards, the FPMWG will accept the site.

b. Until a quantitative analysis is conducted, placement sites be selected following these guidelines:

(1) Dredged material should be placed outside the floodplain of the Mississippi River and tributary streams.

(2) In those cases where in-floodplain placement is found to be necessary, material should be placed in the flood fringe rather than the floodway or effective flow area.

(3) Placement in the floodway or effective flow area is acceptable on a temporary basis. The material must be removed from the floodway before seasonal high water.

Implementation Procedure: Congress must appropriate funds to the Corps of Engineers to prepare quantitative analyses of proposed material placement sites. This task should be carried out as part of recommendation 5.

Rationale: Executive Order 11988 requires that agencies proposing an action that will take place in a floodplain make "adequate provision for the evaluation and consideration of flood hazards" and "include a statement indicating whether the action conforms to applicable State or local floodplain protection standards." This recommendation is based on conclusions reached after work group evaluation of Executive Order 11988. Furthermore, the FPMWG has adopted as its purpose GREAT River Study objective k: "Strive to comply with state floodplain management standards." The guidelines listed in this recommendation are consistent with those standards.

3. The FPMWG recommends that lands along the river that are suitable for stockpiling of dredged material and subsequent removal for beneficial use outside the floodplain be publicly acquired in fee title or easement.

Implementation Procedure: The Plan Formulation Work Group in developing the channel maintenance plan has identified dredged material placement sites on private land that have potential as stockpile sites for beneficial users to obtain material. Congress should appropriate the necessary funds for fee title acquisition or purchase of easements by the Corps of Engineers to ensure that these sites continue to be available for stockpiling. The Corps Office of the Chief of Engineers must change its policy to provide for condemnation of private lands to stockpile dredged material.

Rationale: Although many private landowners along the river have indicated a desire to obtain Corps dredged material, these owners may have future plans for these lands that would preclude their use for dredged material stockpiling and removal. In some cases, landowners plan development for these properties that would be subject to property damage during floods and is clearly in opposition to the goals of floodplain management. In several cases, such as near Homer, Minnesota, in pool 6 and on the Minnesota side of pool 7, there is a need for stockpile sites to be acquired to meet projected demands for dredged material.

4. The FPMWG recommends that the feasibility of removing material from existing disposal sites in the floodway be investigated.

Implementation Procedure: The Upper Mississippi River Master Plan authorized in the Inland Waterway Act (Public Law 95-502) will include a study to demonstrate the feasibility of removing dredged material from the floodplain. The plan of action for this study should be designed to provide funds for the Corps of Engineers, with the approval

of the Upper Mississippi River Basin Commission, to conduct the necessary field studies and investigations into contractor capabilities. Methods that should be considered in this study include contracting for capability to remove material from existing floodway placement sites throughout the St. Paul District, placement of the material on barges for transport to areas of demand, and advertisement that material on certain designated islands is available for any party wishing to remove it. As part of this study, a stockpile of material should be located in an urban area accessible by land and made available to any persons or commercial interests desiring material on a first come-first served basis.

Rationale: In many locations, dredged material continues to accumulate in the effective flow area of the floodplain where it is subject to erosion either back into the channel where it will eventually be redredged or into backwater habitat area. Also, the continued accumulation of material in the effective flow area could affect flood flows by increasing water surface elevations during floods. There are identified and, potentially, unidentified demands for dredged material out of the floodplain, but material is not available to meet those demands. Making material available to the general public at a stockpile site will help to identify the demand in selected locations.

The following recommendations relate to future management and planning on the Upper Mississippi River and are proposed for implementation:

5. The FPMWG recommends that a computerized, hydrologic/hydraulic math model be developed to evaluate the impacts of long-term dredged material placement or other encroachment on the flood-carrying capacity of the Upper Mississippi River 9-foot channel project. The FPMWG supports the feasibility study for and ultimate development of math modeling

for floodplain management purposes proposed by the UMRBC Flood Plain Management Technical Task Force and supports efforts by the UMRBC to obtain funding for this project. On the basis of investigations conducted by the FPMWG, the Compound Stream Flow Model (see Technical Appendix G) is suitable for this purpose and should be investigated as part of the feasibility study.

Implementation Procedure: Congress should provide funds through the UMRBC for the feasibility study and through the Corps of Engineers for development of the model. The Corps of Engineers, in consultation with State floodplain management agencies, the Federal Emergency Management Agency, and the U.S. Geological Survey, will be the implementing agency for the model development and application.

Rationale: The purpose of such a model would be to evaluate the impacts of long-term dredged material placement or other encroachment on the flood-carrying capacity of the river.

A math model of the river for floodplain management purposes will solve the following problems in the Mississippi River floodplain:

- Lack of knowledge of effects of long-term (50-year) placement of dredged material in the floodplain.

- Lack of definition of the hydraulic floodway and encroachment limits for most reaches of the river.

- Lack of knowledge of flood elevations between gaging stations.

- Time and expense involved in case-by-case review and evaluation of individual proposed development projects.

- Inability of local municipalities to provide the necessary resources to deal with floodplain management problems.

- Frequent challenges to decisions to restrict floodplain development which are made without adequate objective data.

(Source: "Recommendations and Supporting Information for a Feasibility Study on Math Modeling of the Mississippi River for Floodplain Management Purposes," unpublished draft, Upper Mississippi River Basin Commission, June 1978.)

The following statements from other sources are offered in support of this recommendation.

From the UMRBC Flood Plain Management Technical Task Force:

> It is the recommendation of the Technical Flood Plain Management Task Force of the Upper Mississippi River Basin Commission that a study be authorized under the authority of the Upper Mississippi River Basin Commission to determine the feasibility of developing a computerized math model or models capable of providing information for floodplain management purposes in the Mississippi River system.

From Main Stem Level B Study draft recommendations:

> A variety of structural and nonstructural measures have been implemented to mitigate flood damages. State and Federal agencies should develop an appropriate mathematical model of the total main stem hydraulic and hydrologic system that would provide a sound data base for future land use management.
>
> Several mathematical models have been developed that would be appropriate for use on the Upper Mississippi River. The UMRBC Flood Plain Management Technical Task Force has prepared a list and description of the various models. (UMRBC, June 1978.)

The FPMWG has considered the various options available in recommending a specific model. The favorable results obtained from the math model pilot study have indicated that the Compound Stream Flow Model has several advantages over the other models considered by the work group. The Compound Stream Flow Model is unsteady state and can account for changes in floodplain storage and sediment transport. The HEC-2 model, most commonly used for floodplain management analyses, is steady state and does not include sediment transport. A combination of HEC-6/HEC-1 requires considerable trial-and-error fine tuning to coordinate the sediment transport, backwater effects, and routing functions. The one-dimensional sediment transport model developed for GREAT I by Colorado State University does not account for flow over the entire floodplain.

The development of such a model must be consistent with the findings of the feasibility study proposed by the UMRBC Flood Plain Management Technical Task Force if such a study is conducted.

> "The development and use of a math model(s) of the Mississippi River would provide a systems approach to the management of the River, providing a sound and consistent analytical tool for use by Federal, State, and local agencies as well as private developers." (UMRBC, June 1978.)

6. Projects in the Mississippi River 9-foot channel floodplain that involve an encroachment or loss of storage should be entered in the mathematical model identified in recommendation 5 to keep the data base current and ensure that cumulative effects of floodplain development are evaluated.

Implementation Procedure: Federal, State, and local agencies should adopt procedures to ensure that all floodplain development is accurately recorded and the data sent to the Corps for inclusion in the math model. This procedure should be accomplished by routing copies of issued permits for fill or development to Corps of Engineers personnel responsible for the operation of the math model.

Rationale: To ensure that the cumulative effects of floodplain development on flood elevations are recorded, public regulatory agencies must forward development information to the Corps of Engineers. Any runs of the model made without including added development will not accurately reflect river conditions during floods.

7. Uniform standards for floodplain management should be developed for States and municipalities along the GREAT I portion of the Mississippi River. Changes in enabling legislation may be necessary.

Implementation Procedure: The State agencies of Minnesota, Wisconsin, and Iowa that have responsibility for floodplain management are responsible for implementation of this recommendation.

Rationale: At the present time, allowable floodplain encroachment limits are different in each of the three States. However, the effects on water stages of administration of standards on one side of the river are the same on both sides of the river. There is no existing framework for resolution of inconsistencies in standards other than through the courts. Effective floodplain management cannot be applied by the municipalities if standards for encroachment are not uniform across the floodplain.

The FPMWG has addressed this issue and recognizes the need for consistency in application of standards on both sides of the river. Following are statements offered in support of this recommendation.

From the National Forum on the Future of the Floodplain, September 1975:

> The workshop strongly recommends the adoption of a policy that will encourage multiagency efforts that can bring to bear appropriate sources of funding and expertise to accomplish objectives not obtainable by single agencies.

From Upper Mississippi River Comprehensive Basin Study vol. V, Appendix I:

Establish a flood control organization to administer State floodway encroachment and dam safety provisions, coordinate flood damage reduction activities with Federal and local government, and assist in the procurement of needed flood data for the enactment of local ordinances.

8. Detailed topographic and hydrographic maps of the Upper Mississippi River bottomlands in the GREAT I area should be produced. The maps should be at a scale no smaller than 1:12,000 (1 inch = 1,000 feet) on an orthophoto base with contour intervals of 2 feet. The maps should be produced in a format facilitating their use by the general public. Costs of production should be recovered through sales of published maps to the general public.

Implementation Procedure: Congress should appropriate money to the U.S. Geological Survey to accomplish this task.

Rationale: These maps would have several purposes related to management of the Mississippi River bottomlands. The information could be used to define cross section dimensions for floodplain management math modeling. The alternative to obtaining cross sections from maps is to conduct field surveys as needed. The maps would also be useful to recreational users of the river, especially fishermen and hunters. Fish and wildlife managers would find the maps useful in quantifying existing habitat and planning for improvements or creation of additional habitat in critical areas. This information base would also serve the needs of State agencies and local units of government in planning, management, and regulatory activities.

There has already been a public demand for copies of the GREAT I base maps.

It is estimated that partial costs of producing the maps could be offset by selling the published maps to the general public. This approach is used by the Geological Survey in production of topographic quadrangle sheets. An appropriate format for the maps would be one similar to the navigation chart booklets published by the Corps of Engineers.

9. Streambank erosion control measures should be implemented to reduce bed load sediment entering the Mississippi River from the Chippewa and Wisconsin Rivers, Wisconsin; Zumbro and Root Rivers, Minnesota; and Upper Iowa River, Iowa.

Implementation Procedure: The U.S. Department of Agriculture, Soil Conservation Service, should be the lead agency, coordinating with the Corps of Engineers.

Rationale: This recommendation is based on FPMWG conclusion 5 regarding the effects of tributary sediment contributions on the flood-carrying capacity of the Mississippi River. The intent of this recommendation is to lend the support of the FPMWG to the recommendations of the SEWG regarding streambank erosion control. Reduction in bed load sediment entering the main stem from tributaries will reduce dredging requirements in the navigation channel. Reduced dredging volumes will result in less material placed in the floodplain.

10. The FPMWG, in accordance with a recommendation of the Public Participation and Information Work Group, recommends that stream channelization or straightening projects that are proposed for tributaries of the Mississippi River in the GREAT I area be evaluated to determine:

a. Potential increases in tributary flood flows resulting from the project.

b. Potential increases in the bed load sediment transport capability of the tributary stream resulting from the project.

Implementation Procedure: The Soil Conservation Service and U.S. Army Corps of Engineers should change their policies concerning planning of stream channelization projects by adding a provision to their environmental impact statement preparation guidelines incorporating the provisions of this recommendation.

Rationale: The FPMWG concluded that stream channelization projects that result in increased tributary discharges could adversely affect flood flows on the main stem by increasing the hydrograph peak of slope of the hydrograph. Increased bed load transport capability of tributaries could result in greater dredging requirements in the navigation channel which, in turn, would result in increased amounts of dredged material placed in the floodplain. These potential impacts must be weighed as costs of construction in planning these projects.

IX. REFERENCES

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Simons, D. B. and Y. H. Chen, Hydrological Study of the Weaver-Belvidere Area, Upper Mississippi River, Colorado State University, Fort Collins, Colorado, December 1977.

AD-A126 968 GREAT I: A STUDY OF THE UPPER MISSISSIPPI RIVER VOLUME 2 FLOODPLAIN MANAG..(U) GREAT RIVER ENVIRONMENTAL ACTION TEAM SEP 80

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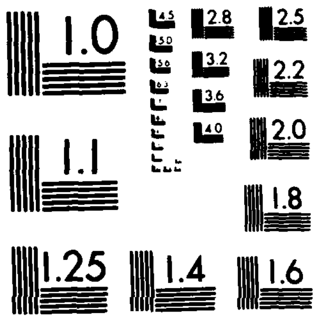

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Upper Mississippi River Basin Commission, Recommendations and Supporting Information for a Feasibility Study on Math Modeling of the Mississippi River for Floodplain Management Purposes, June 1978.

Upper Mississippi River Comprehensive Basin Study Coordinating Committee, Upper Mississippi River Comprehensive Basin Study, Appendix I: Flood Control, Volume V, 1970.

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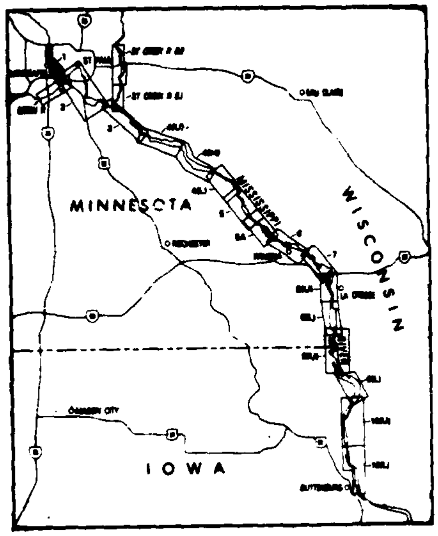
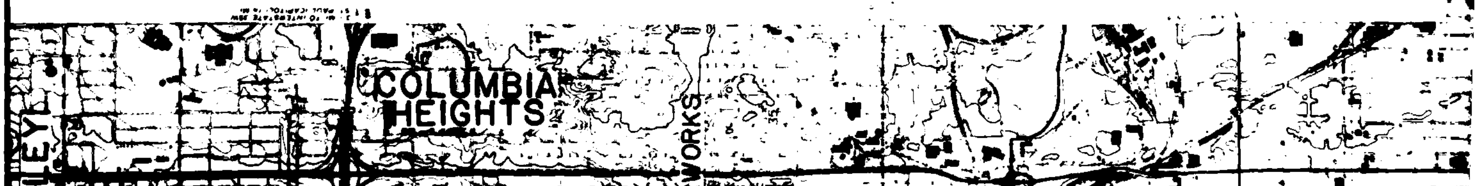
APPENDIX E

FLOODPLAIN-FLOODWAY MAPS





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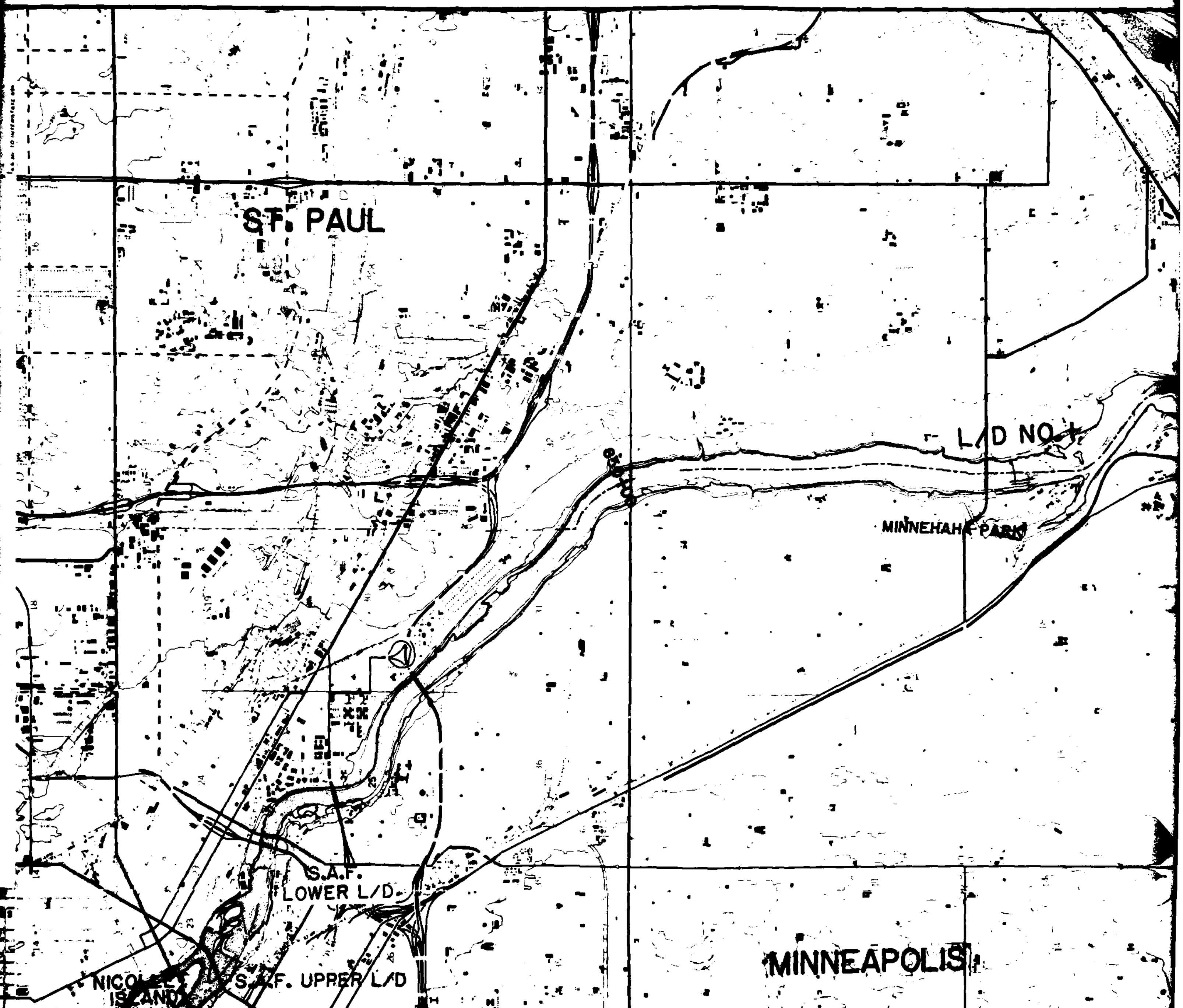

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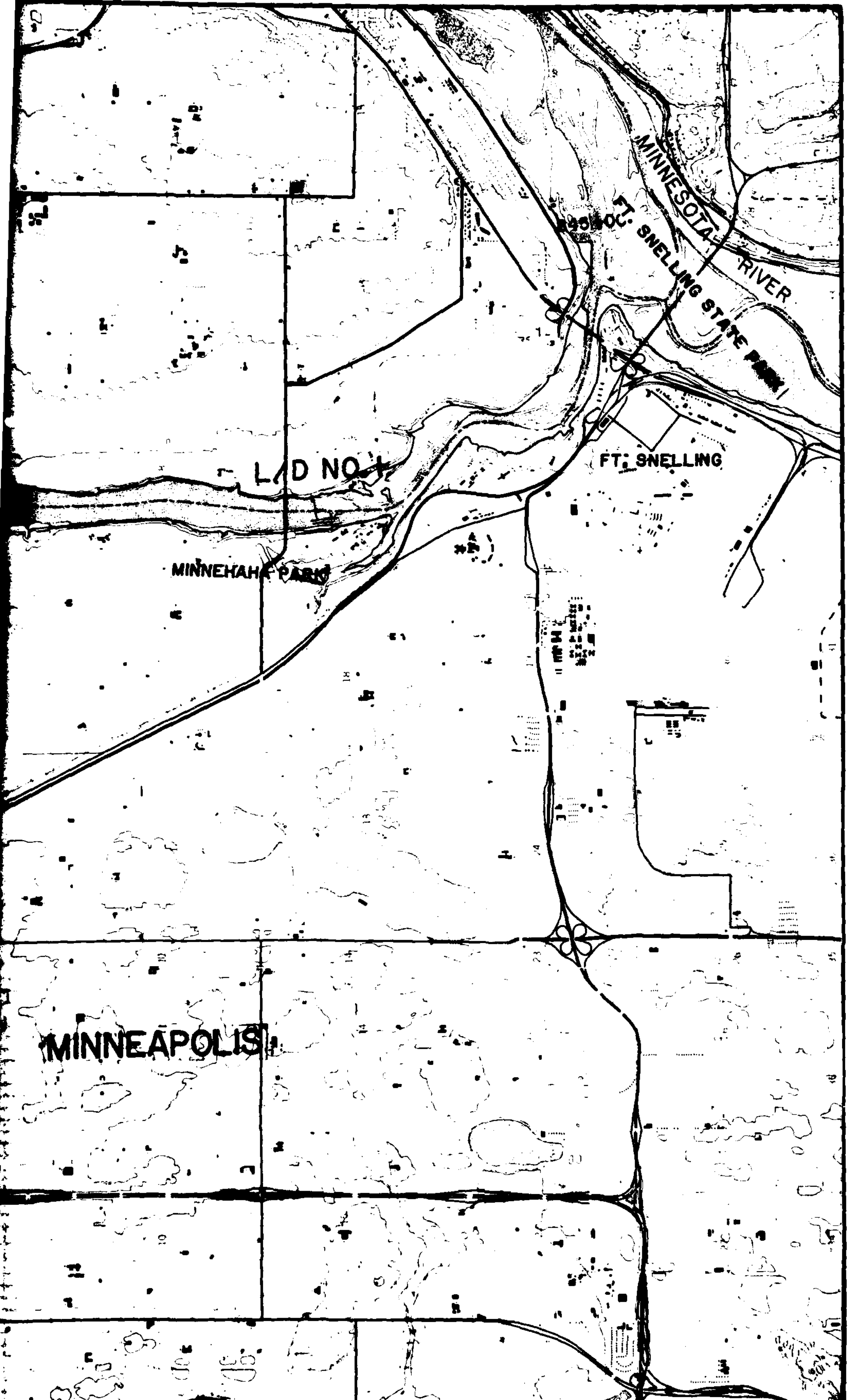

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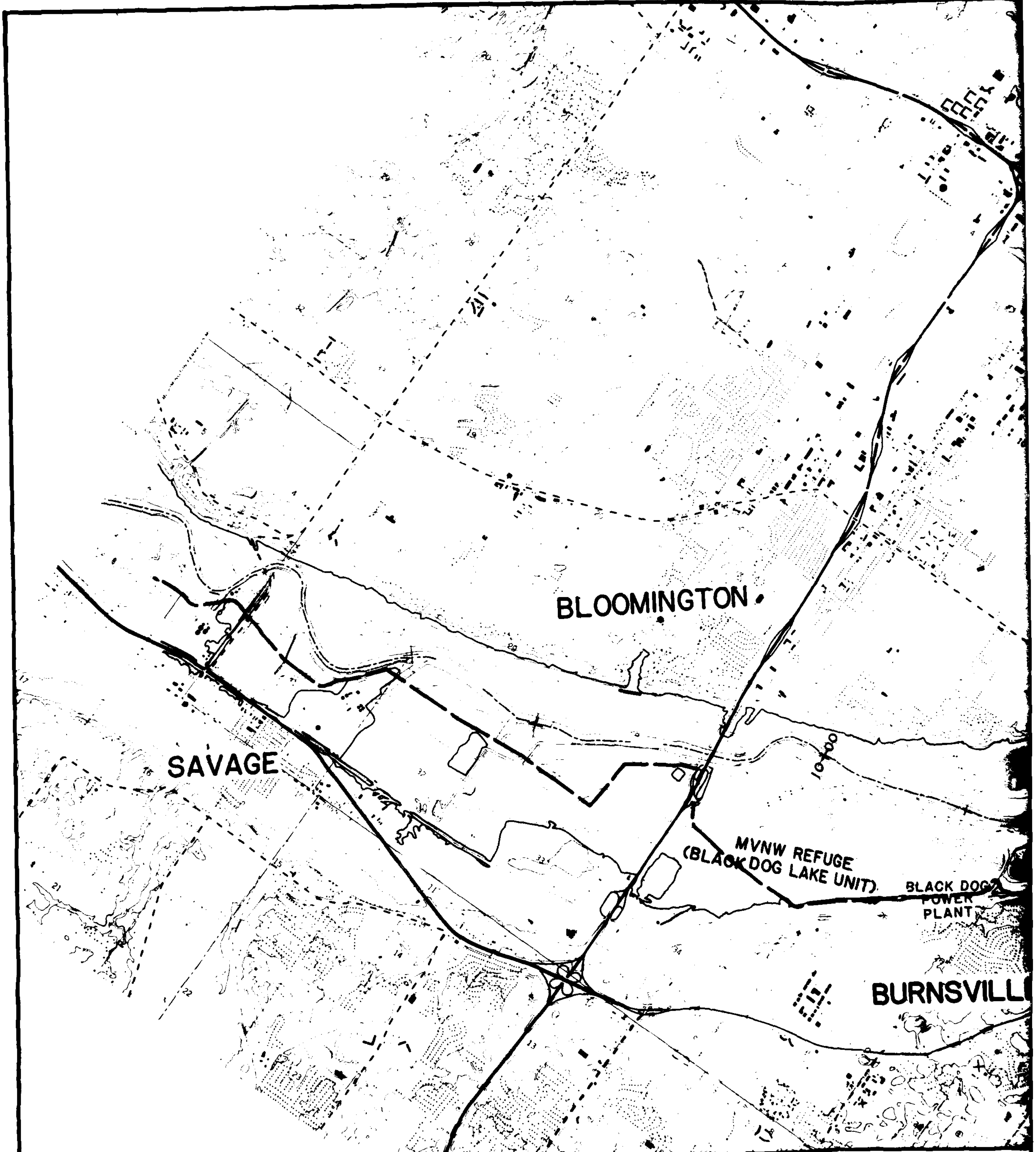

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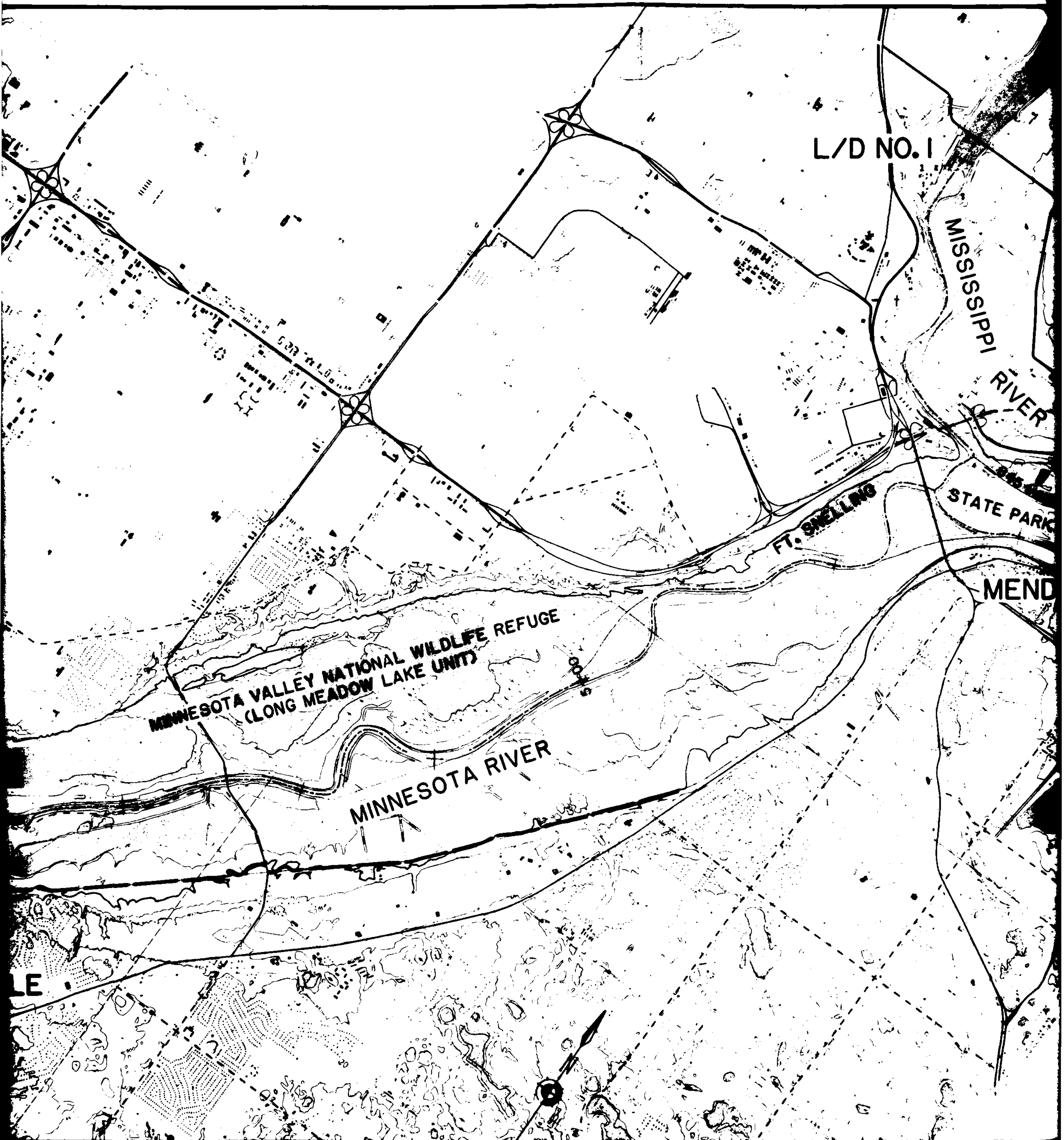

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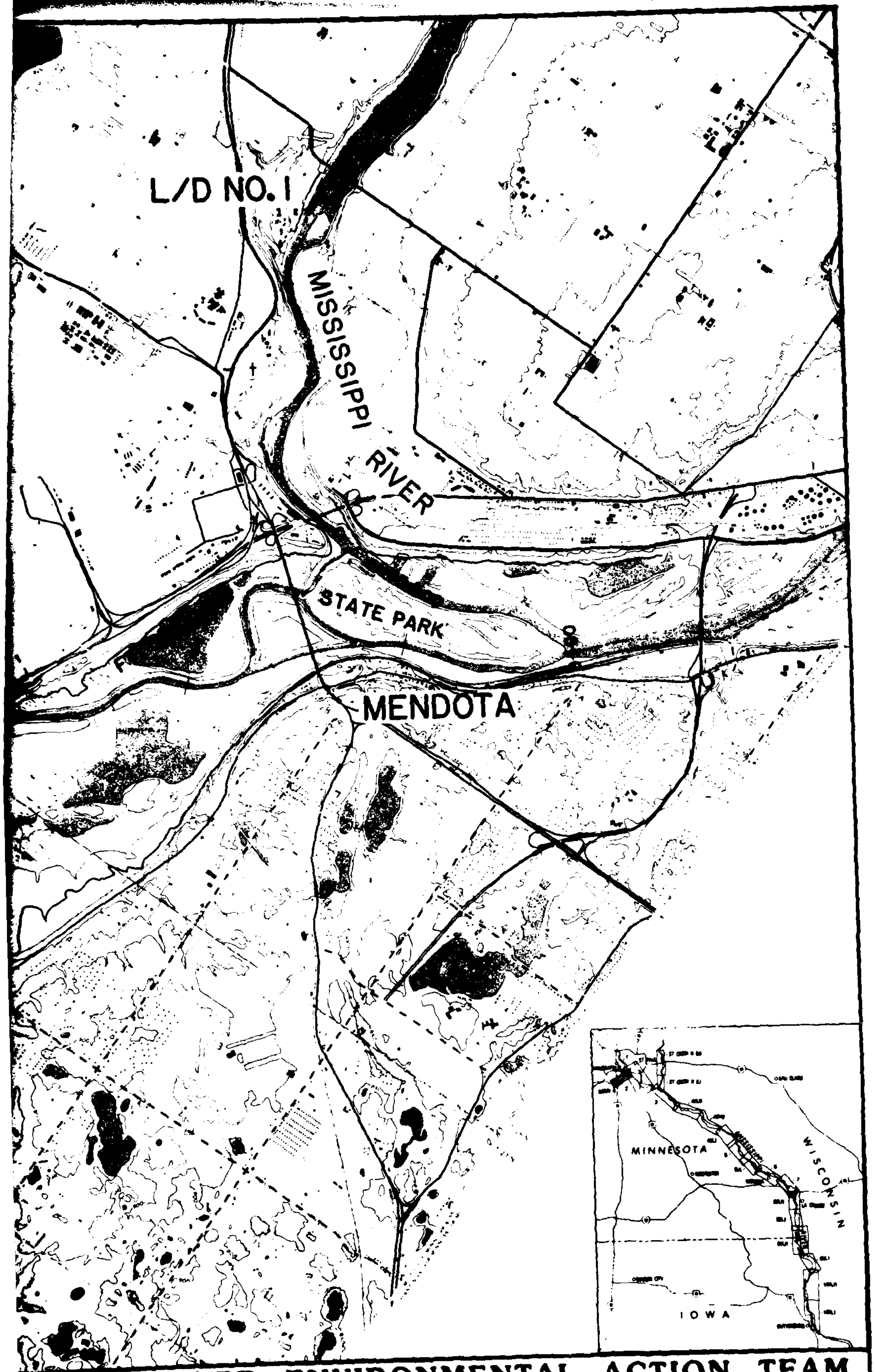

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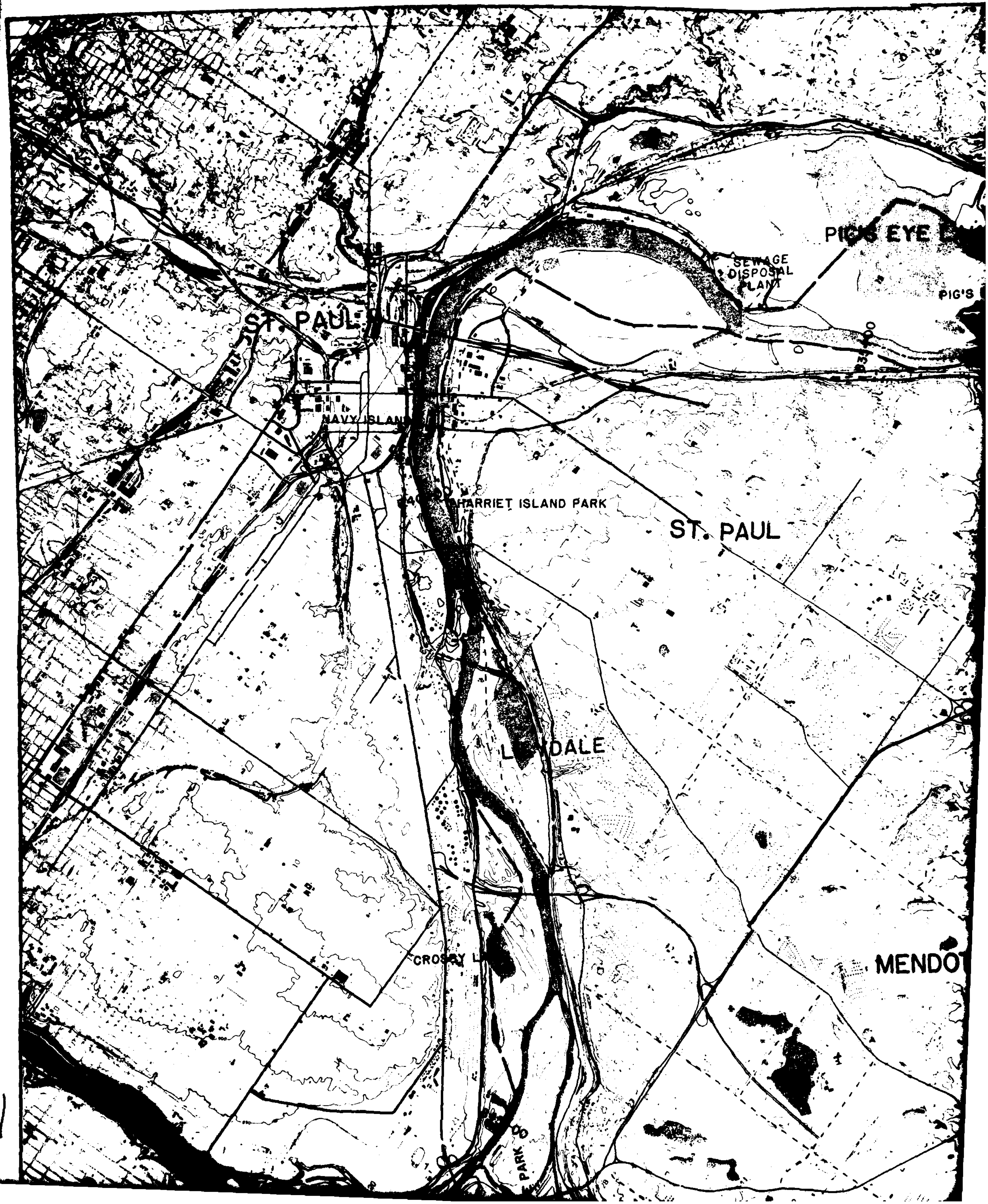
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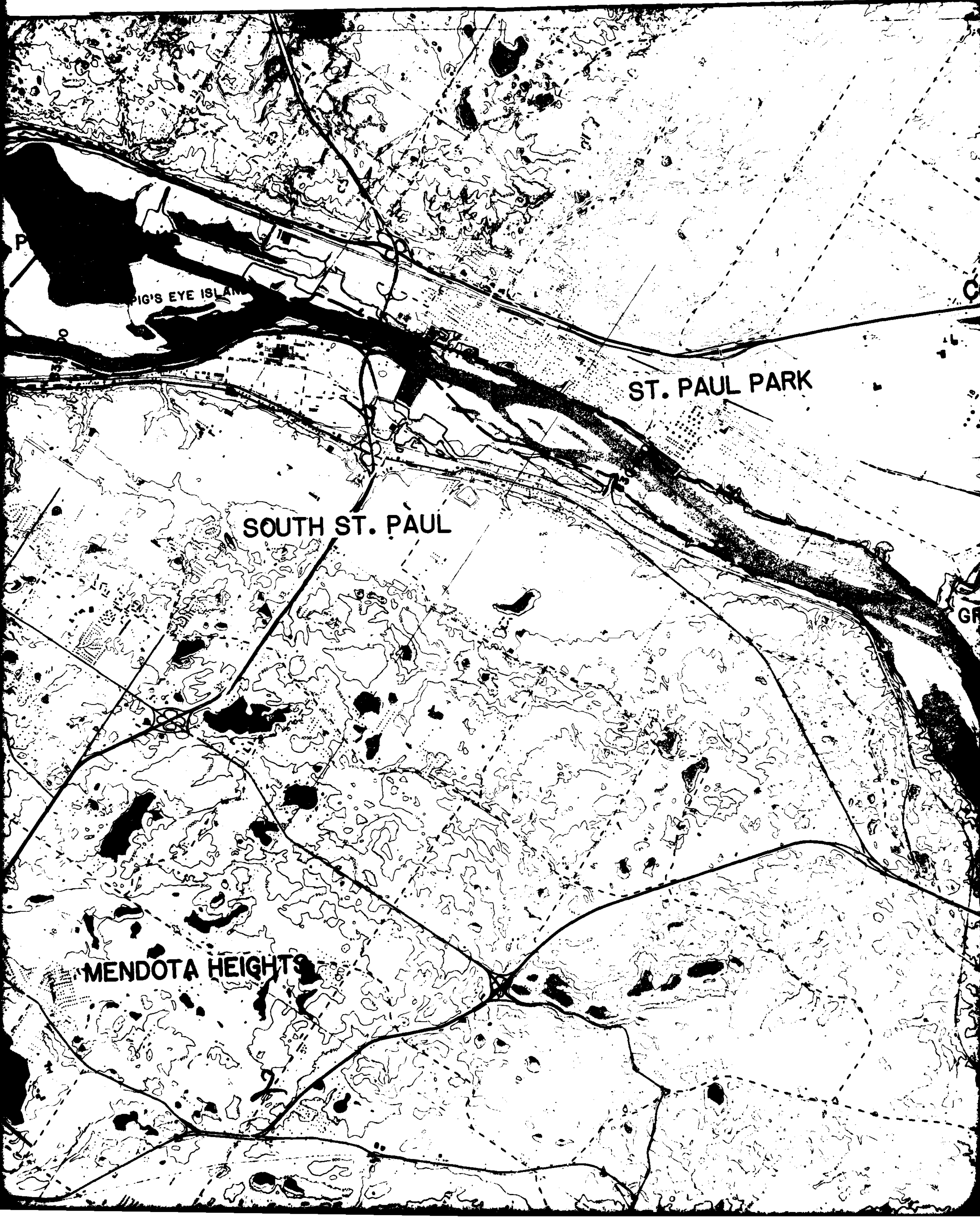
PIG'S EYE
SEWAGE DISPOSAL PLANT
PIG'S
NAVY ISLAND
HARRIET ISLAND PARK
ST. PAUL
PARK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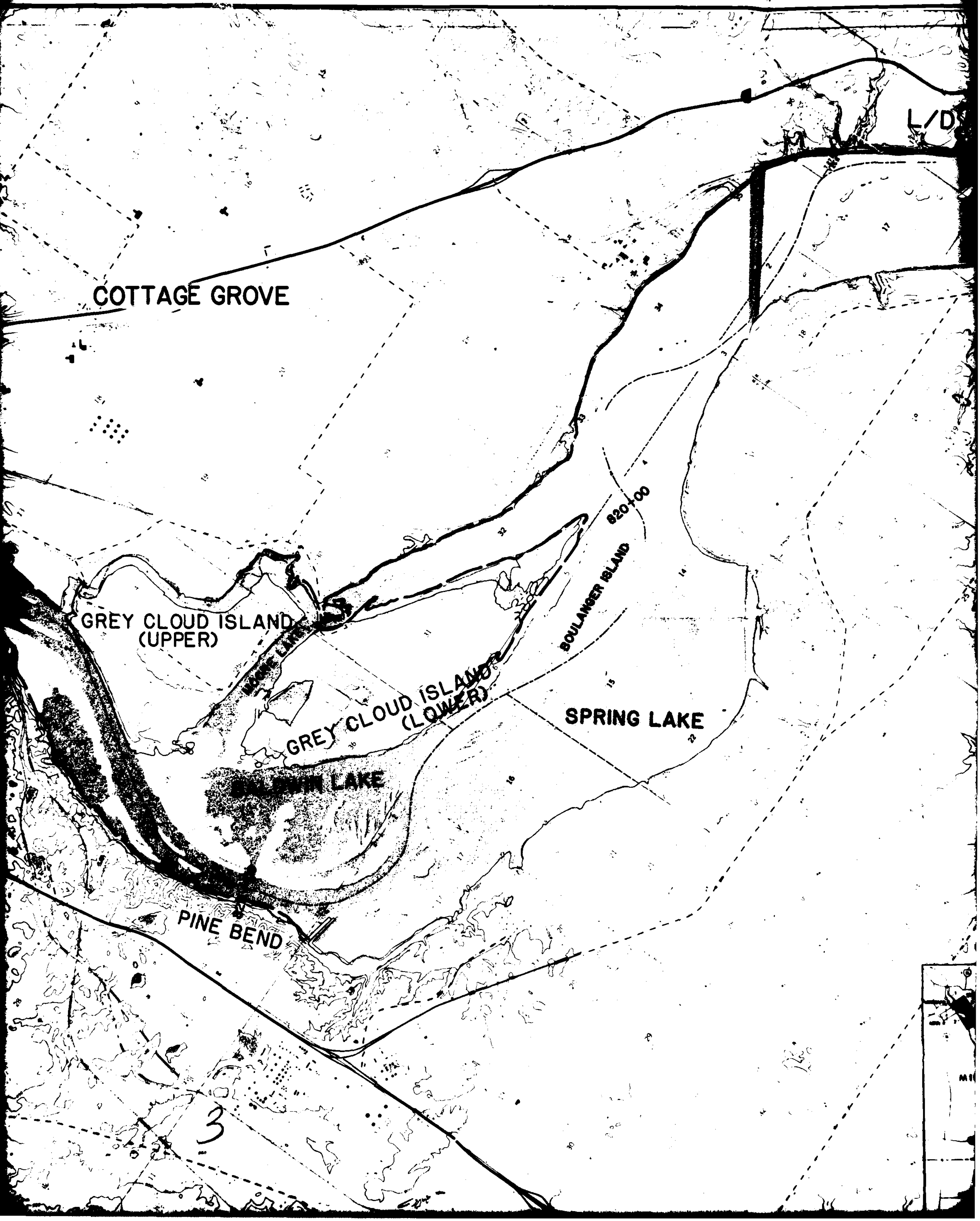
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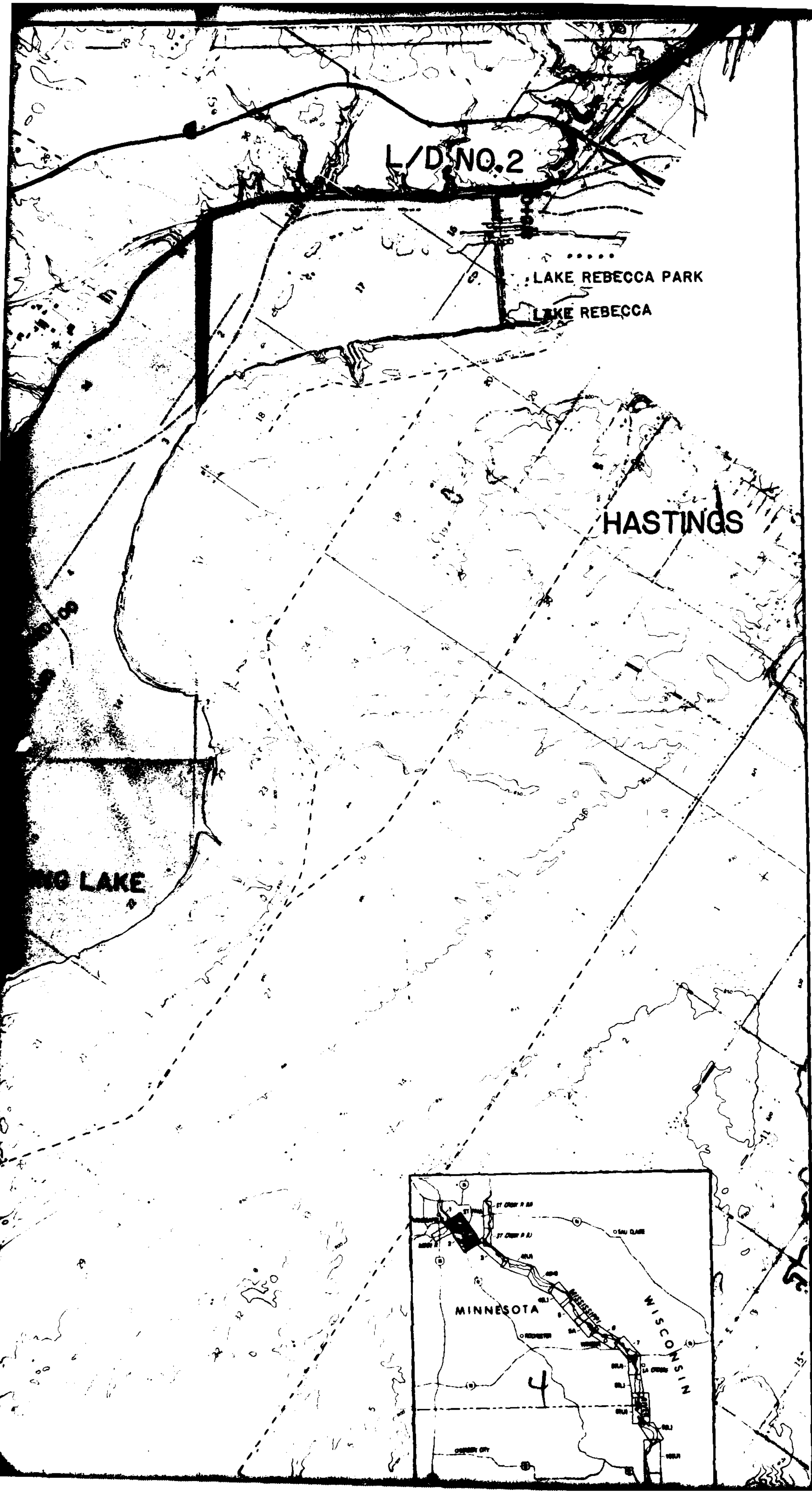
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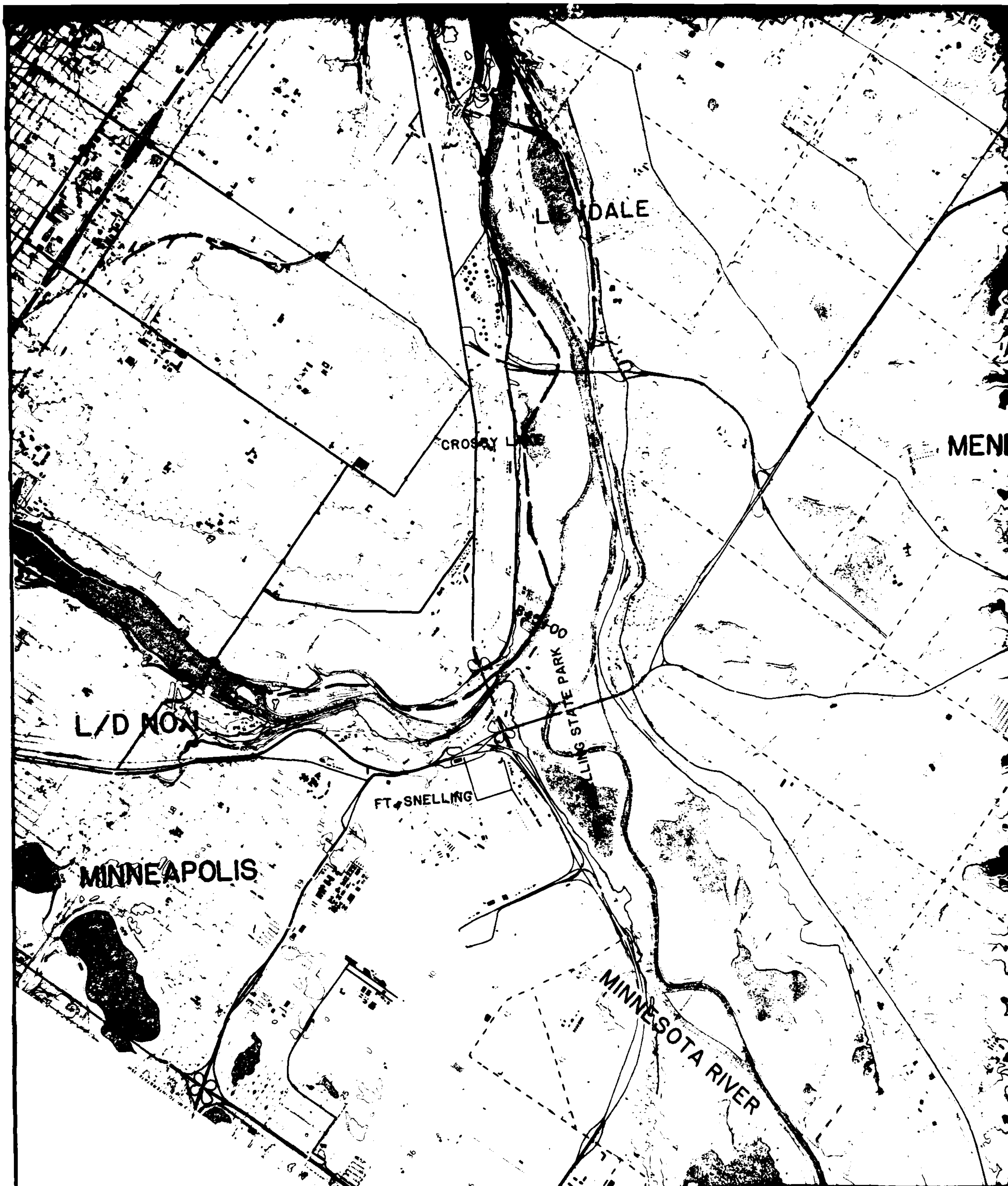

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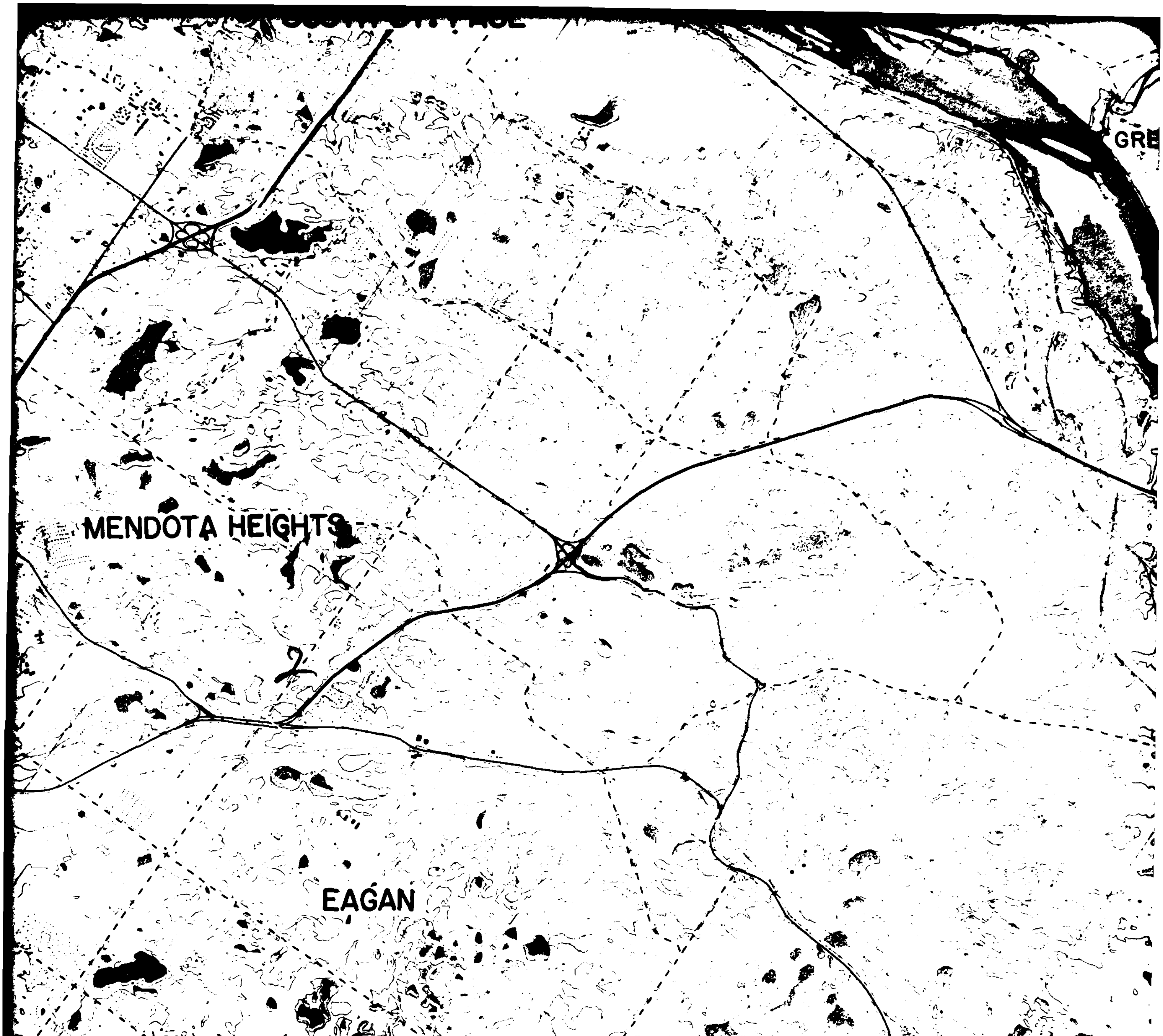

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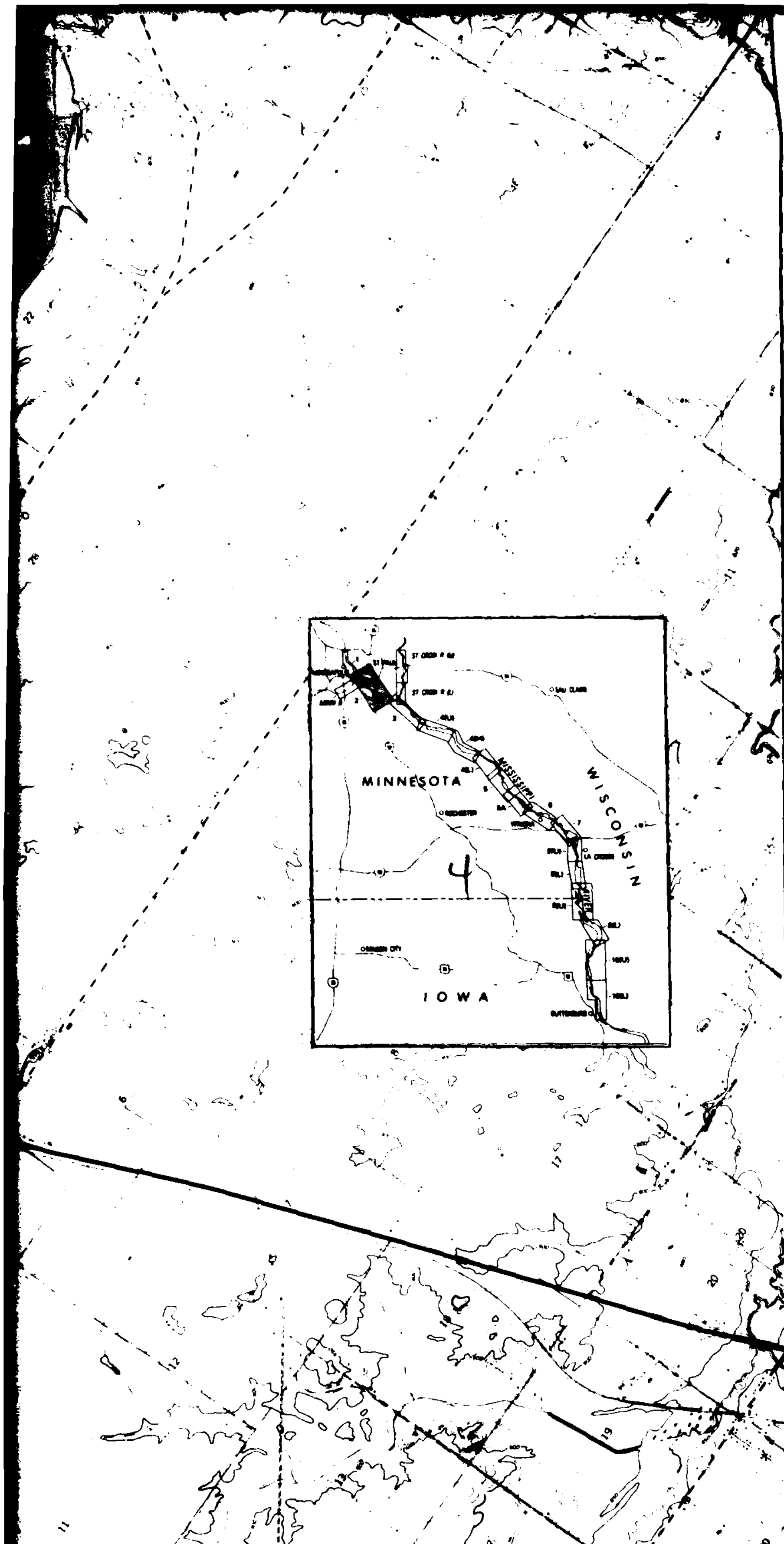

RIVER ENVIRONMENTAL ACTION TEAM
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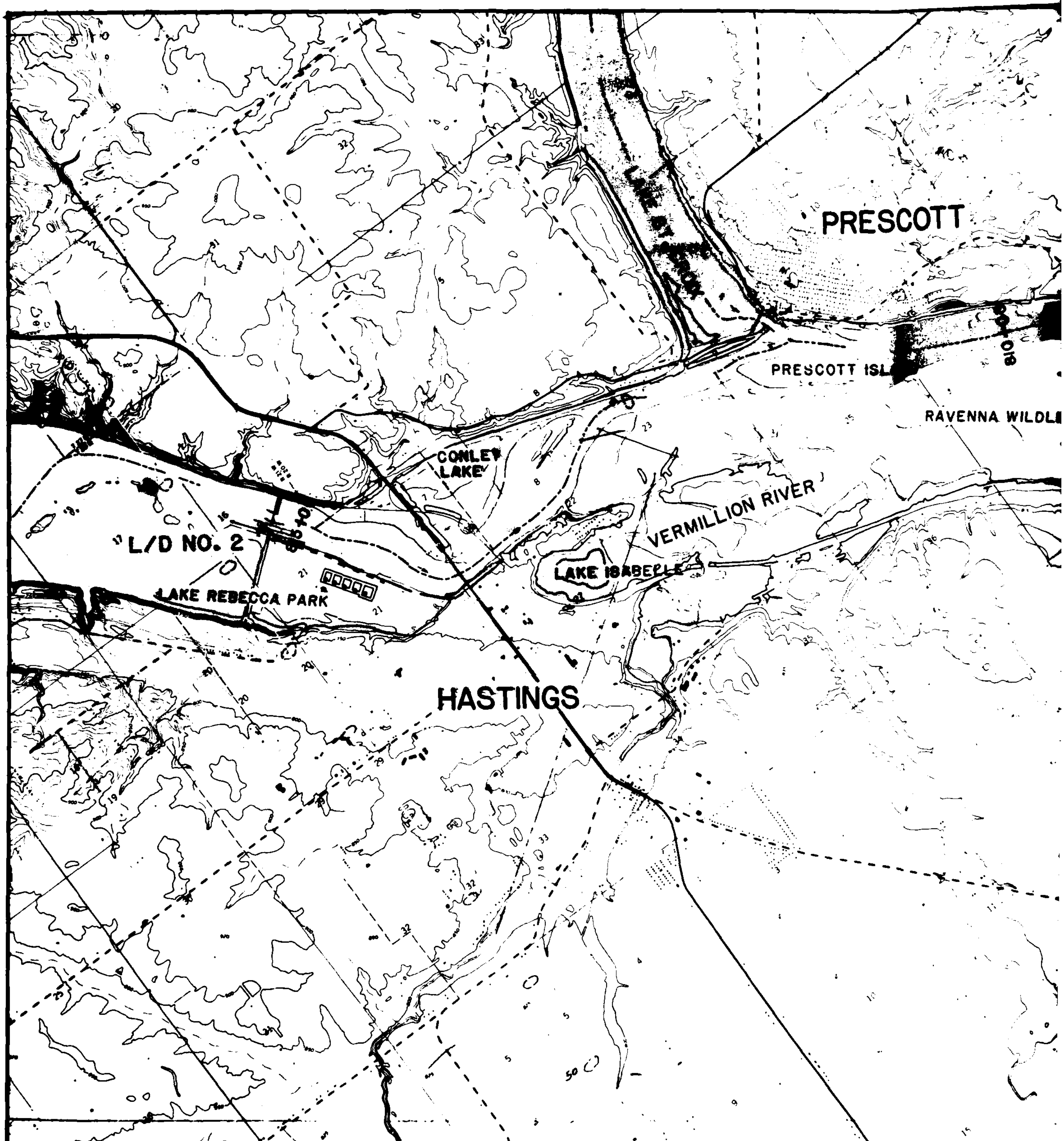

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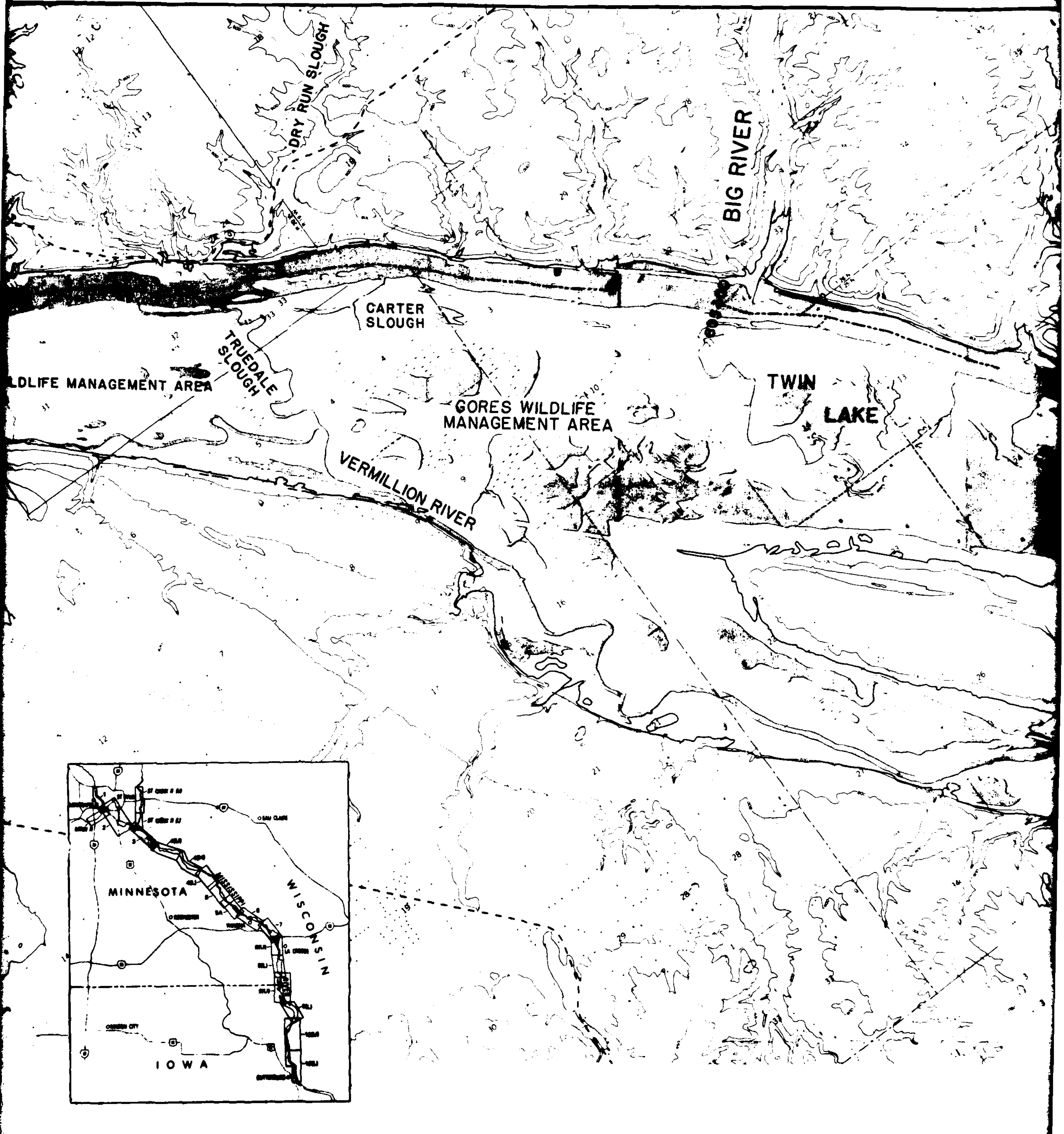
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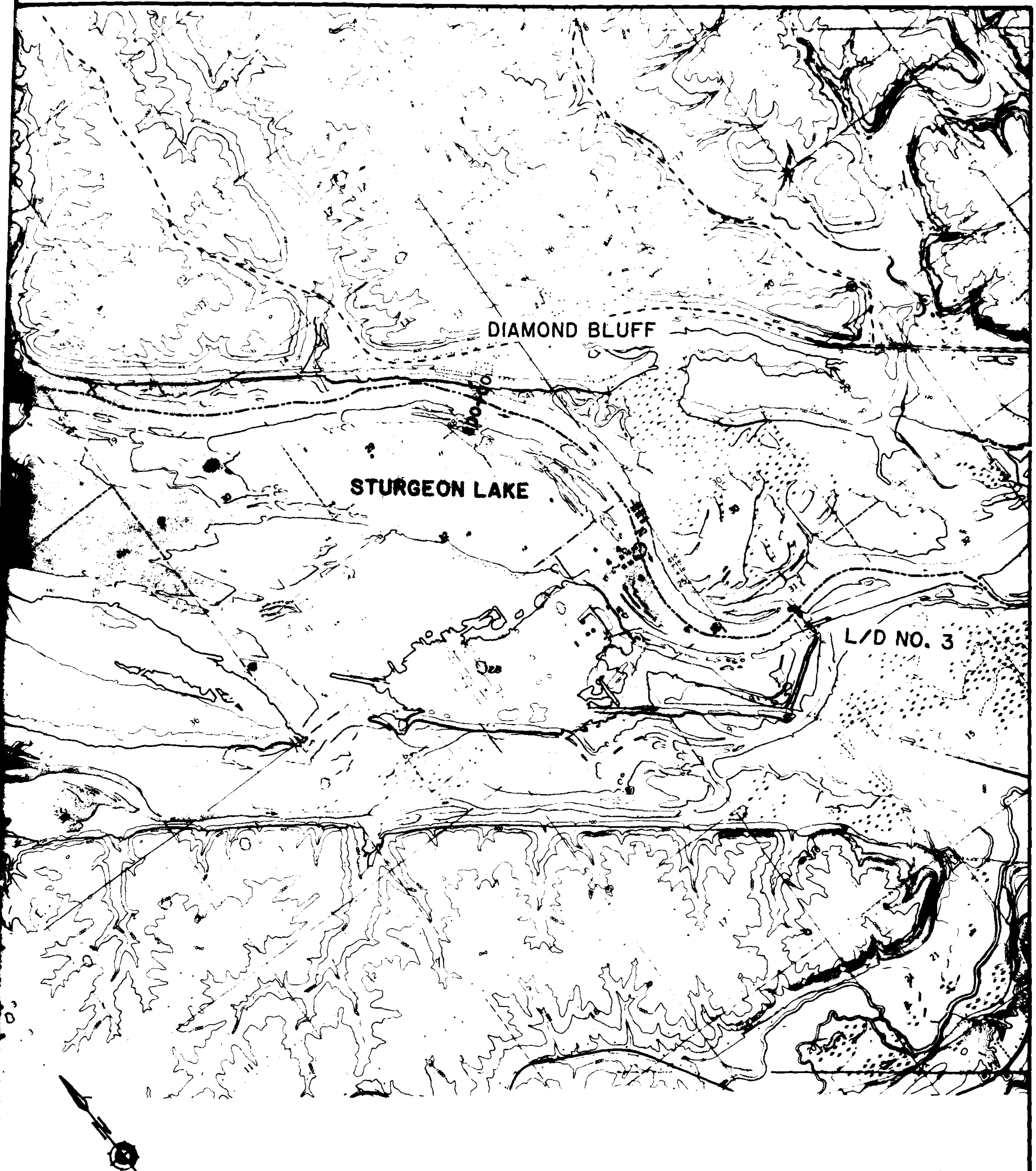

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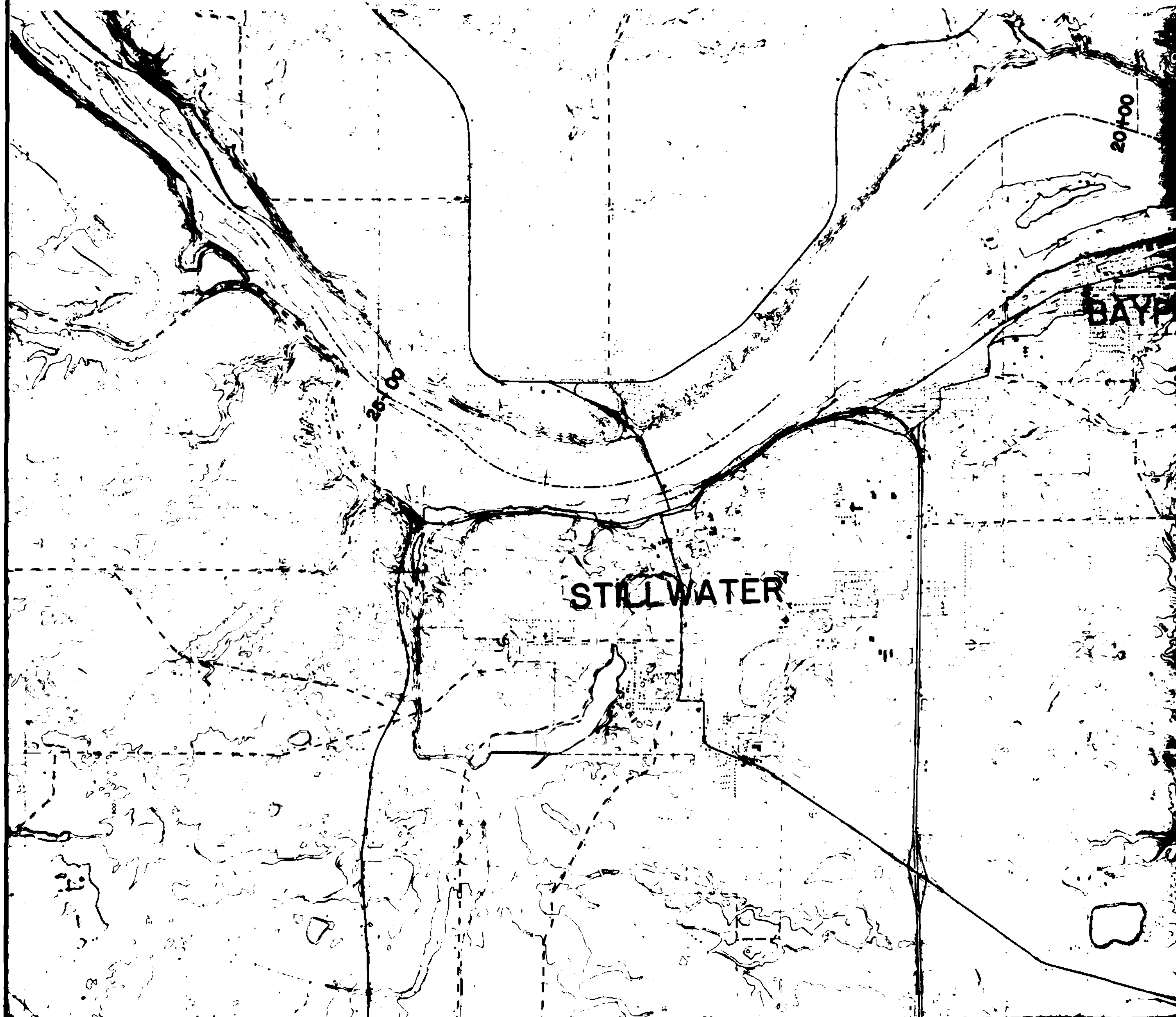

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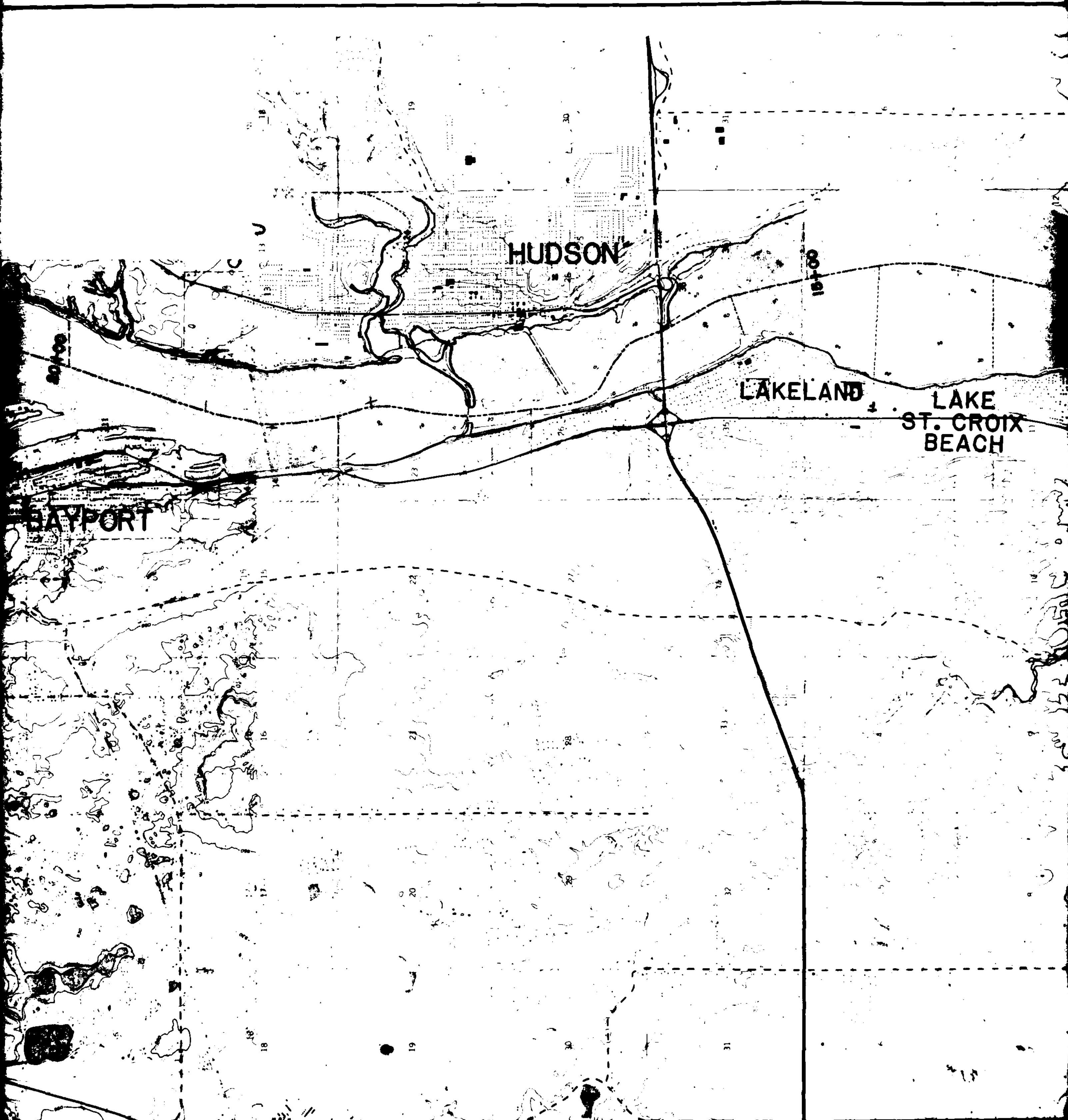

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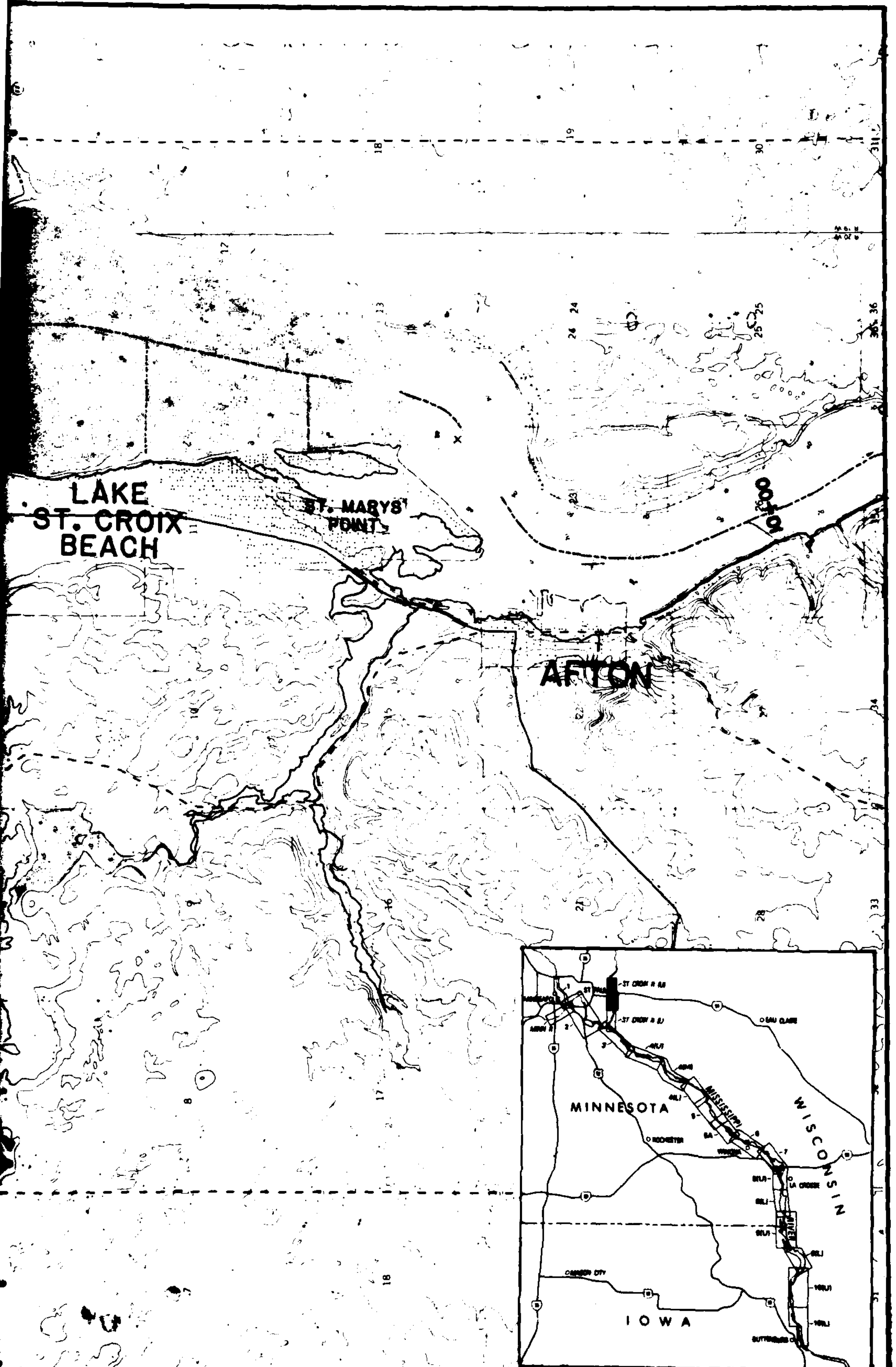

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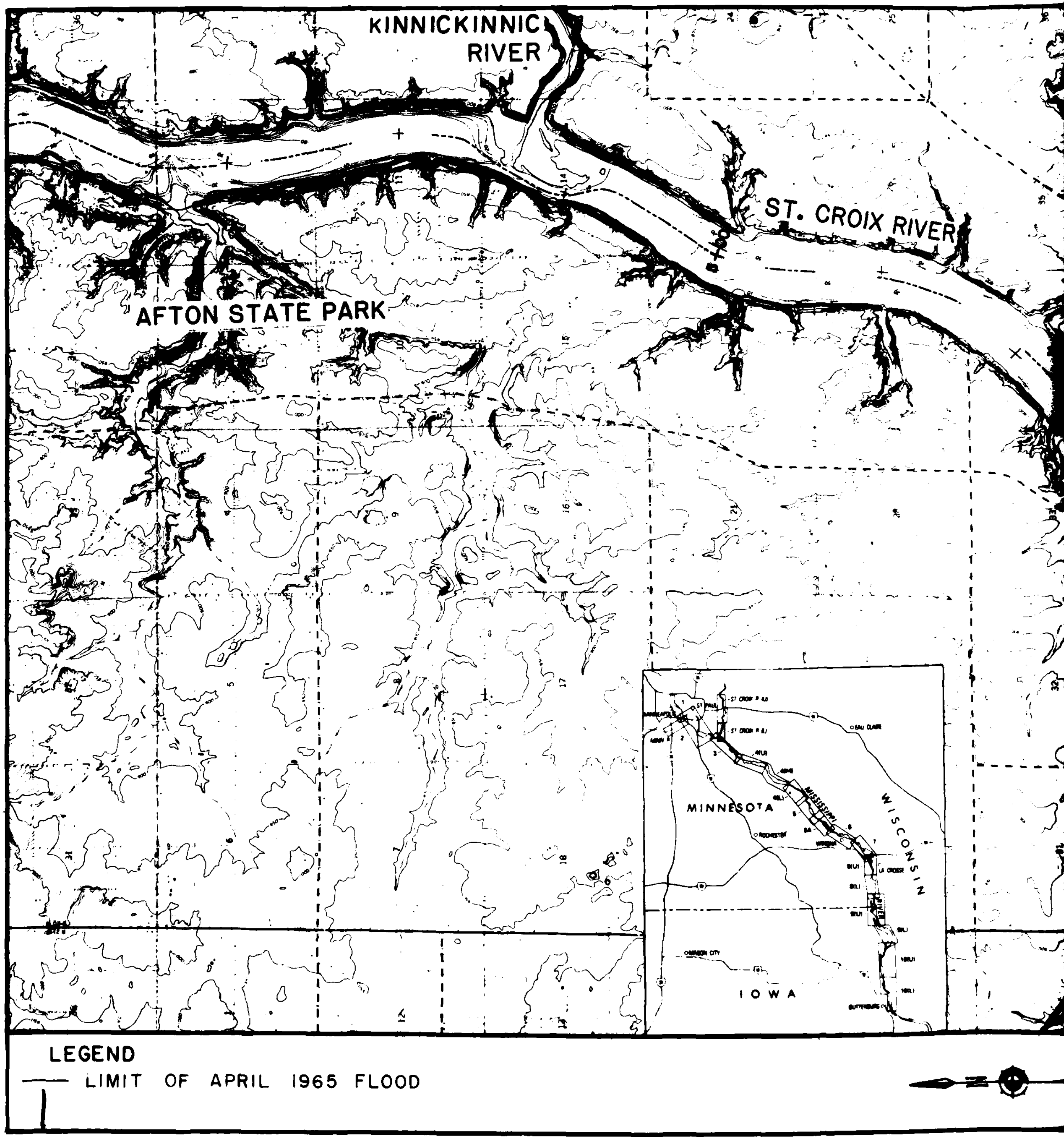
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MASON CITY
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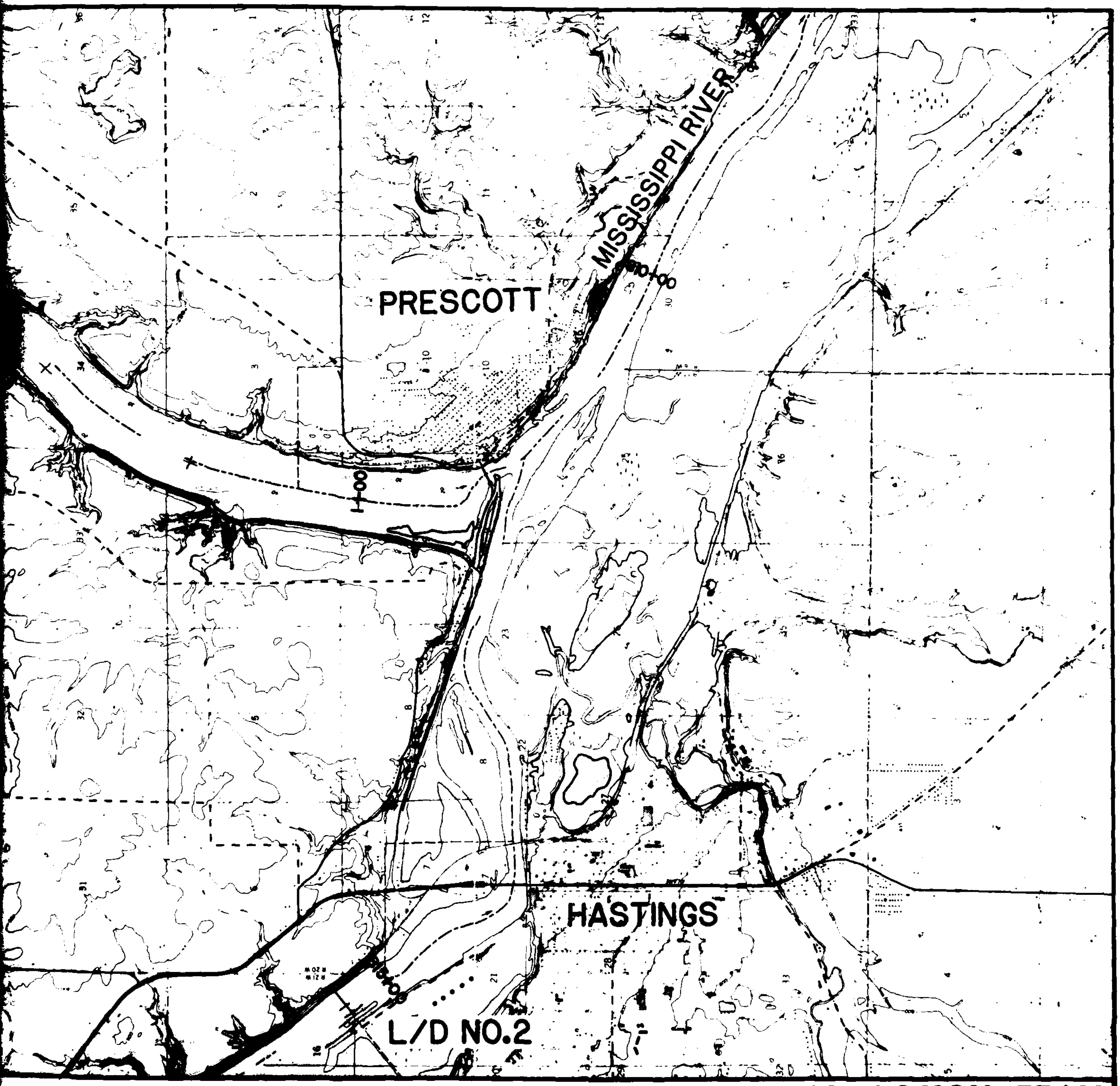
LIMIT OF APRIL 1965 FLOOD



GREAT RIVER ENVIRONMENTAL ACTION TEAM
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(MILE 0 TO MILE 9)

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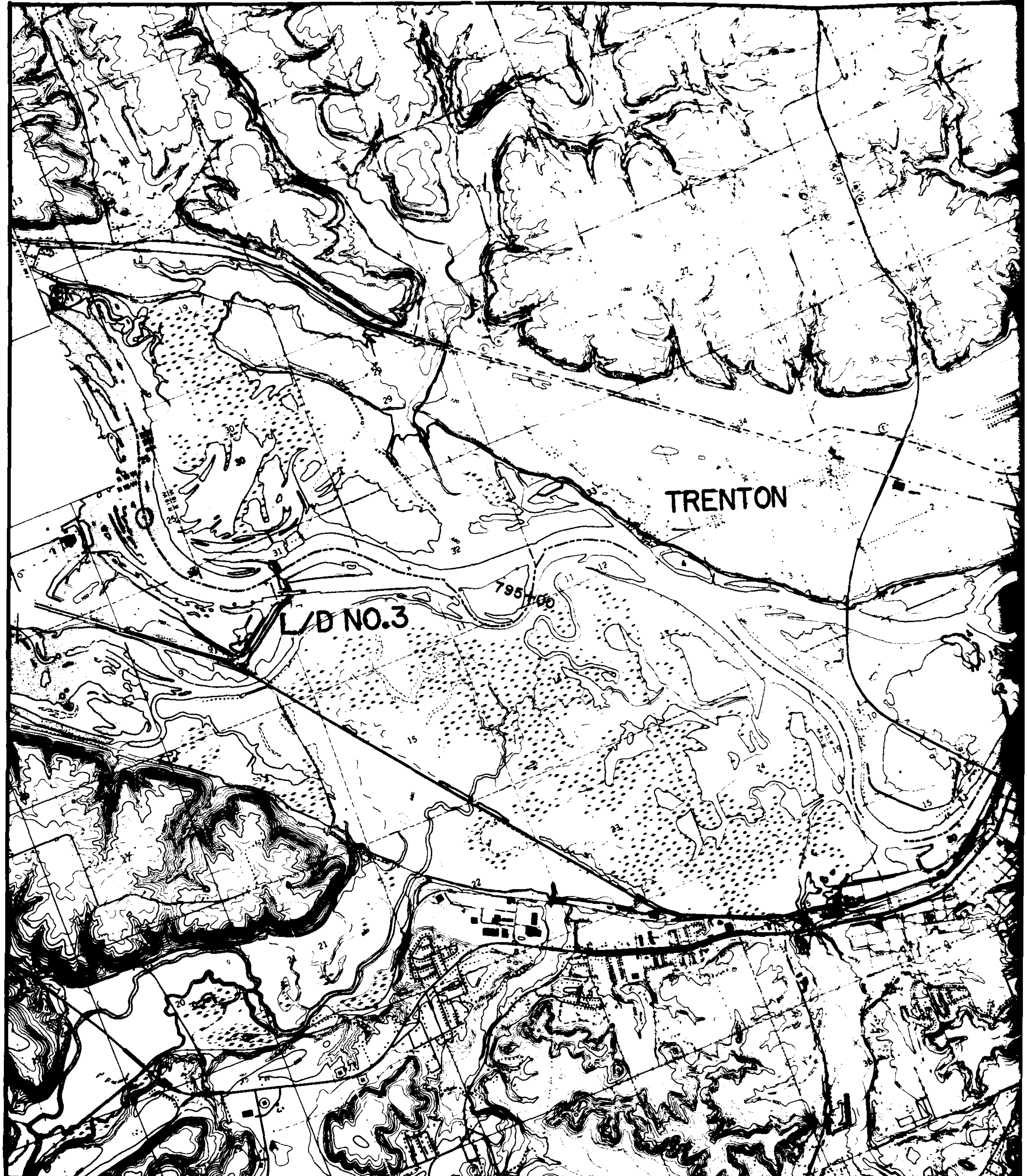

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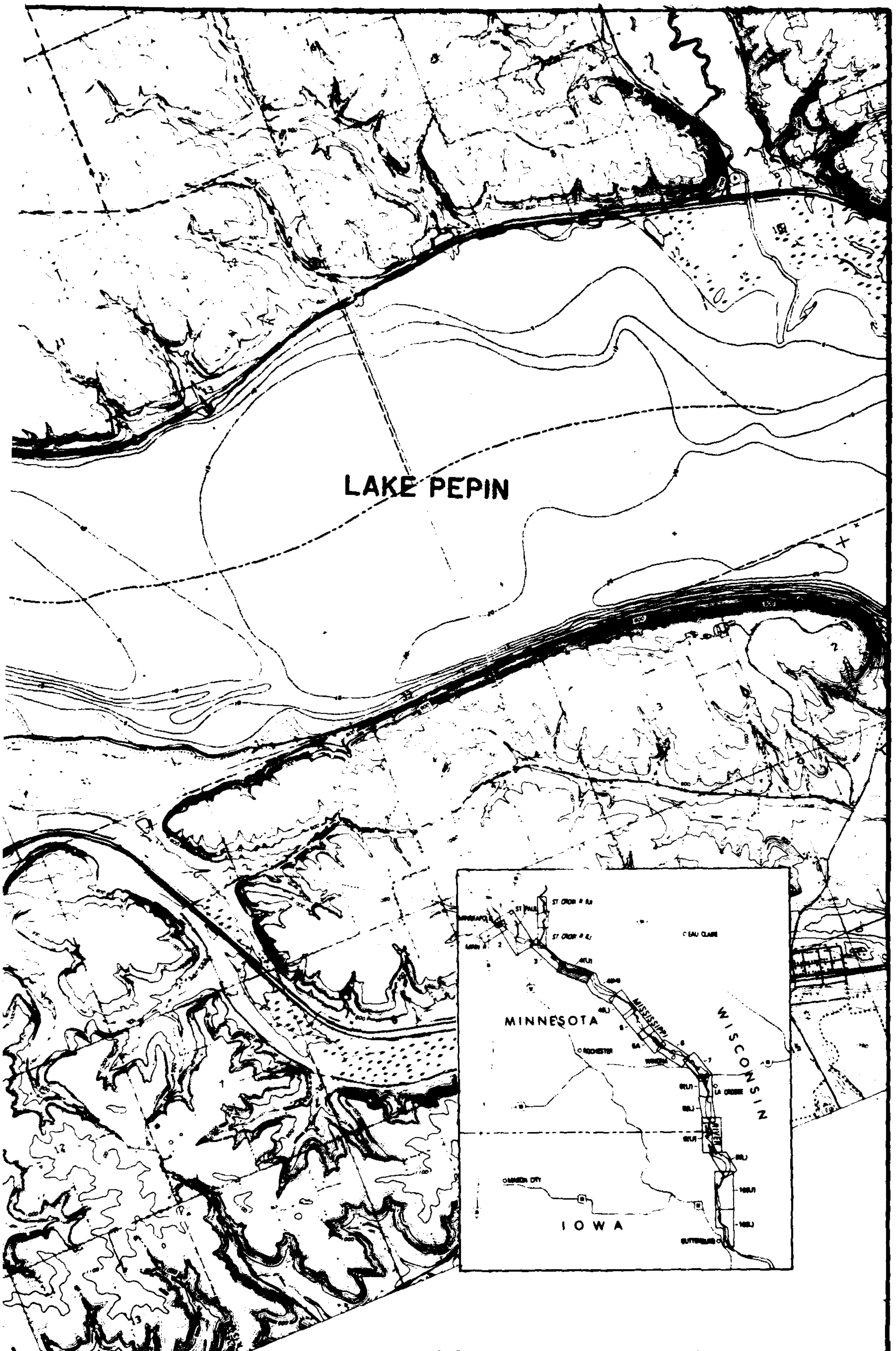

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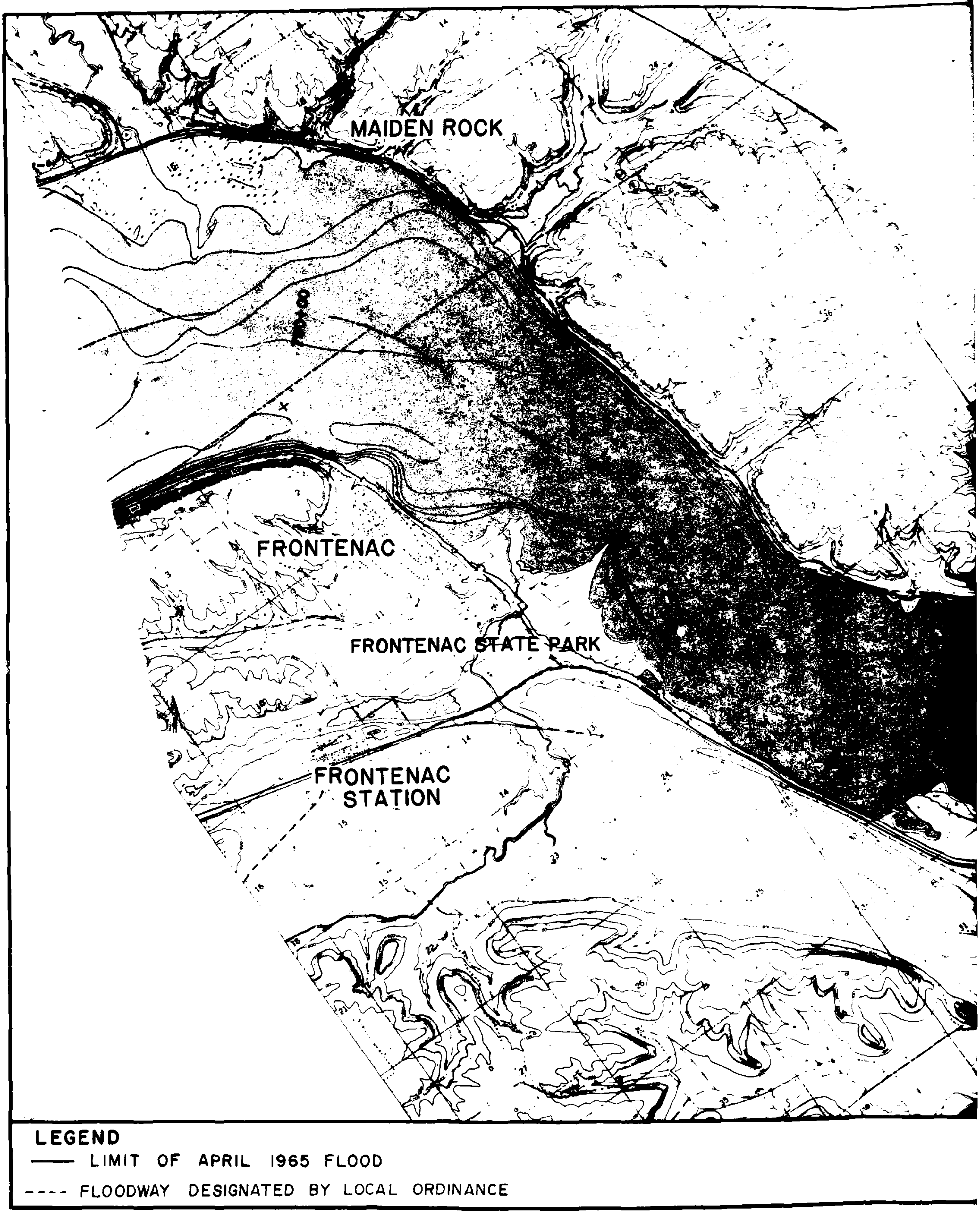
(POOL 4(U)—MILE 781 TO MILE 797)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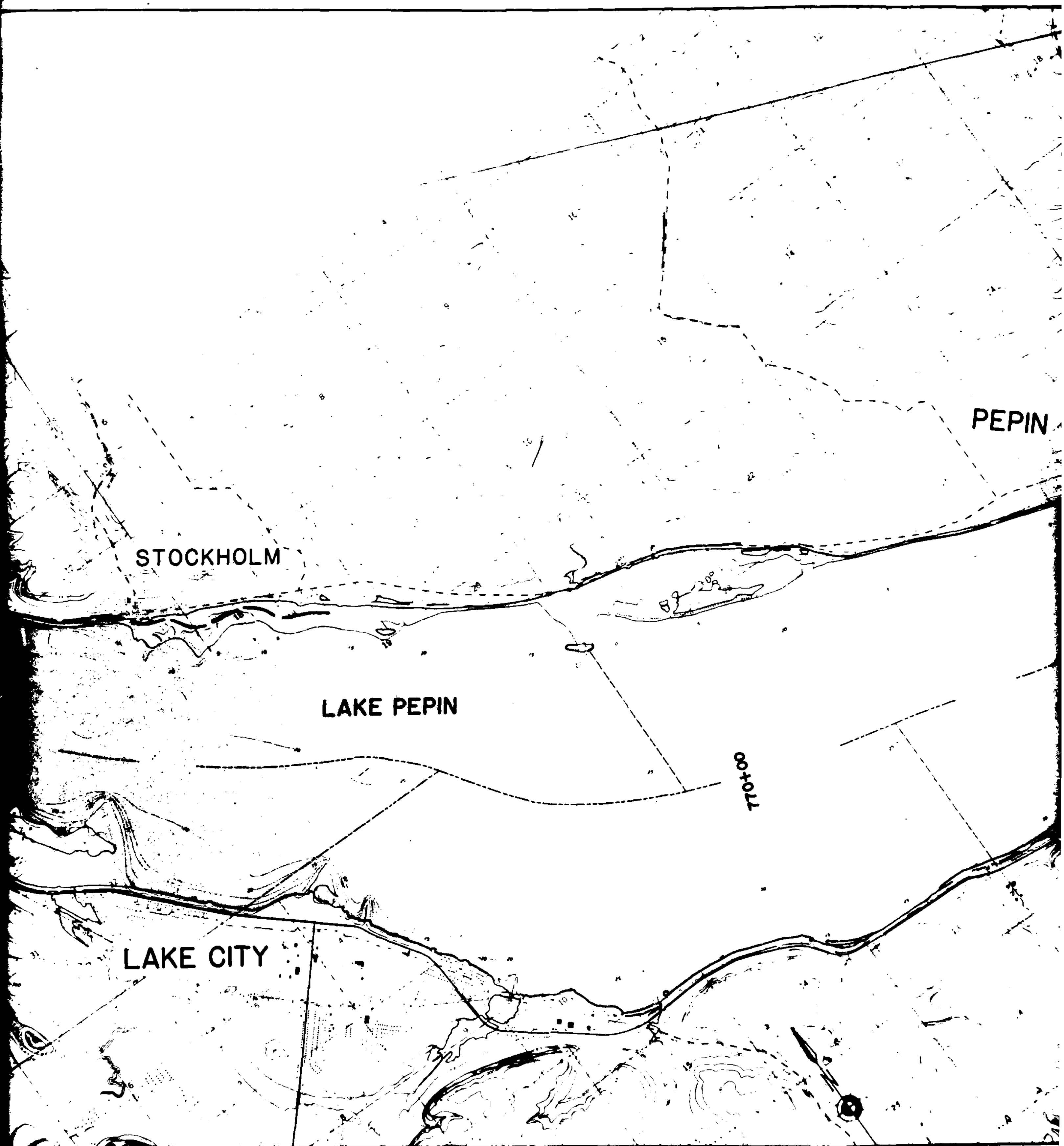

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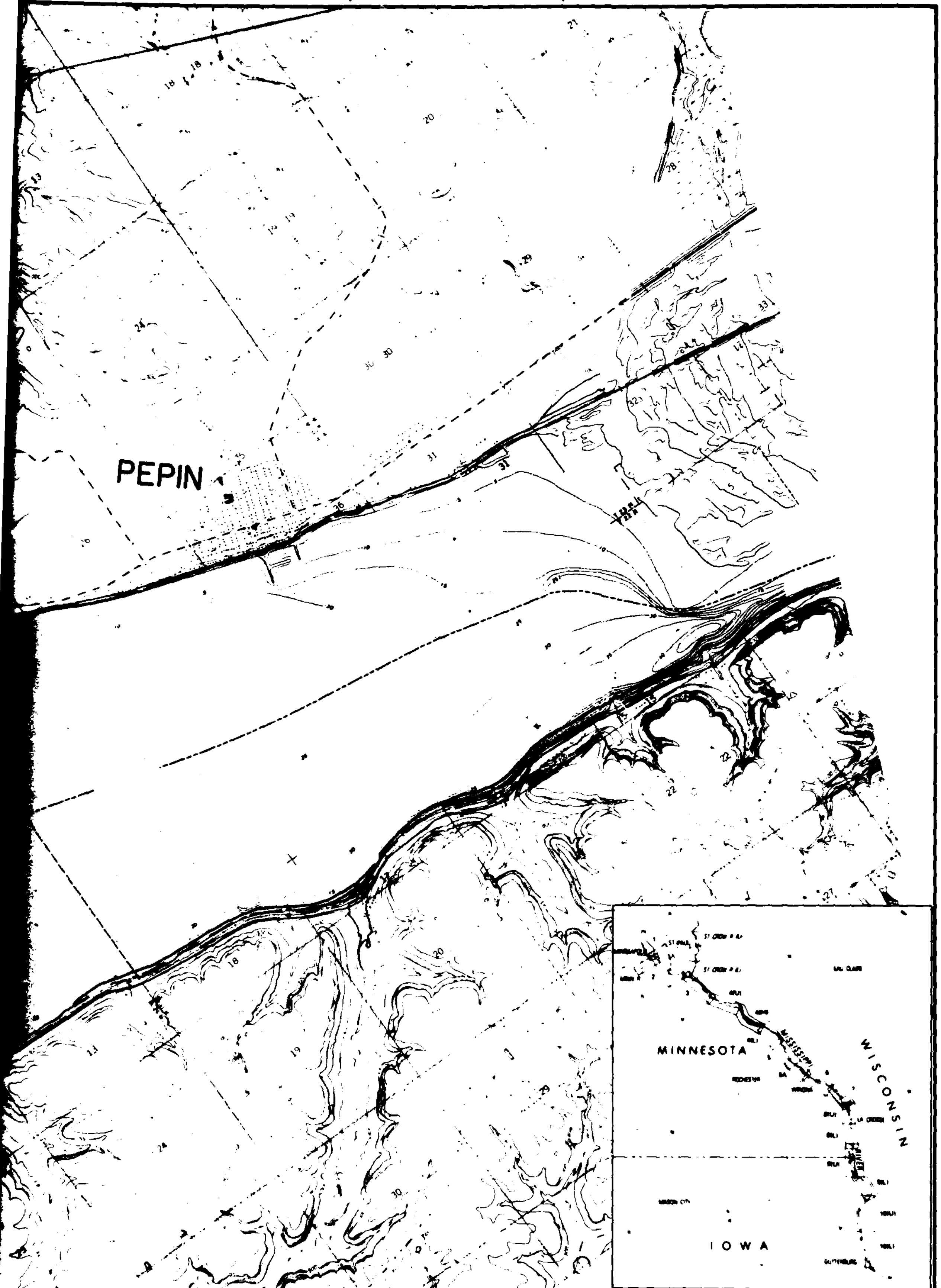

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(POOL 4(M)-MILE 766 TO MILE 780)

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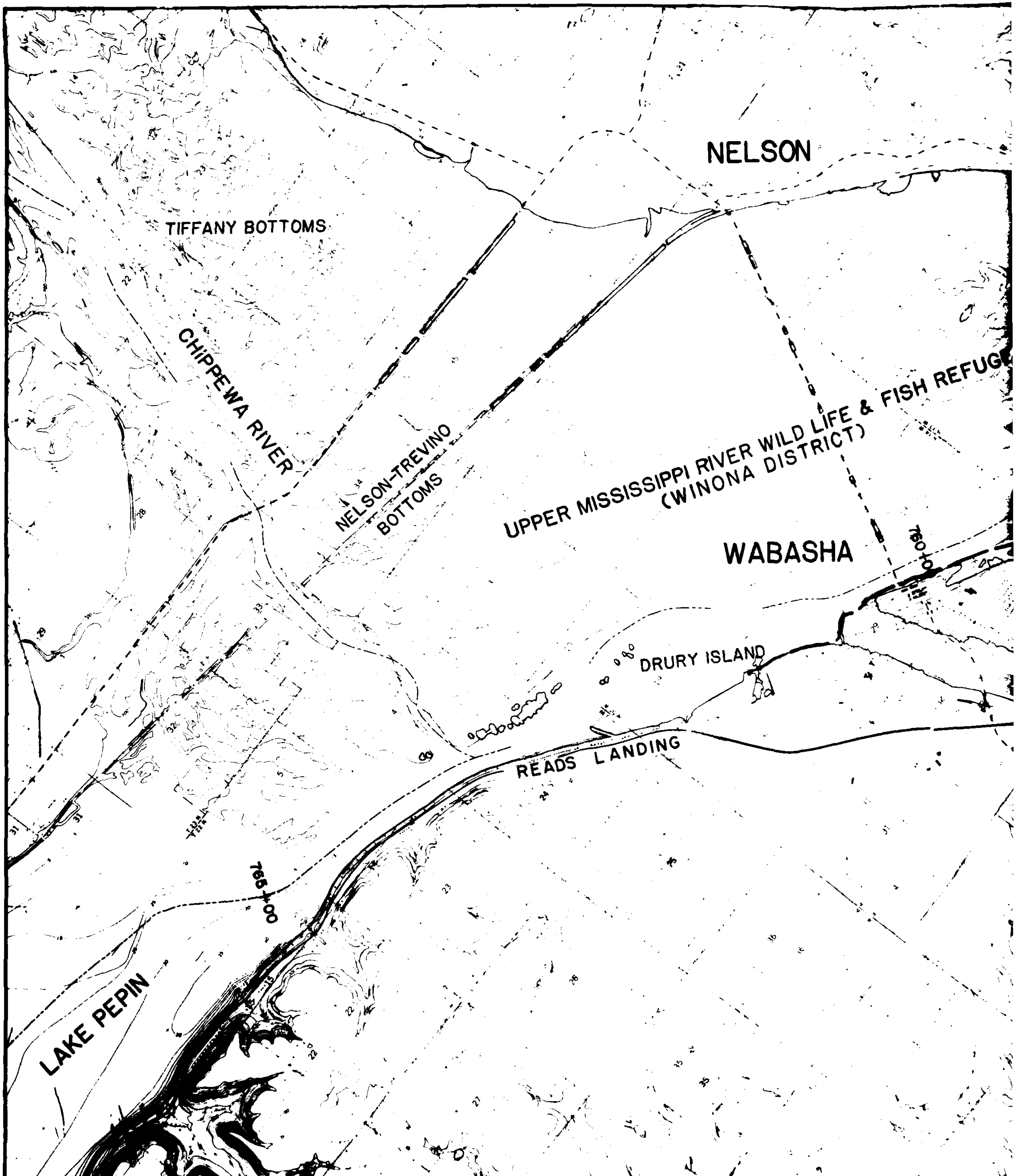

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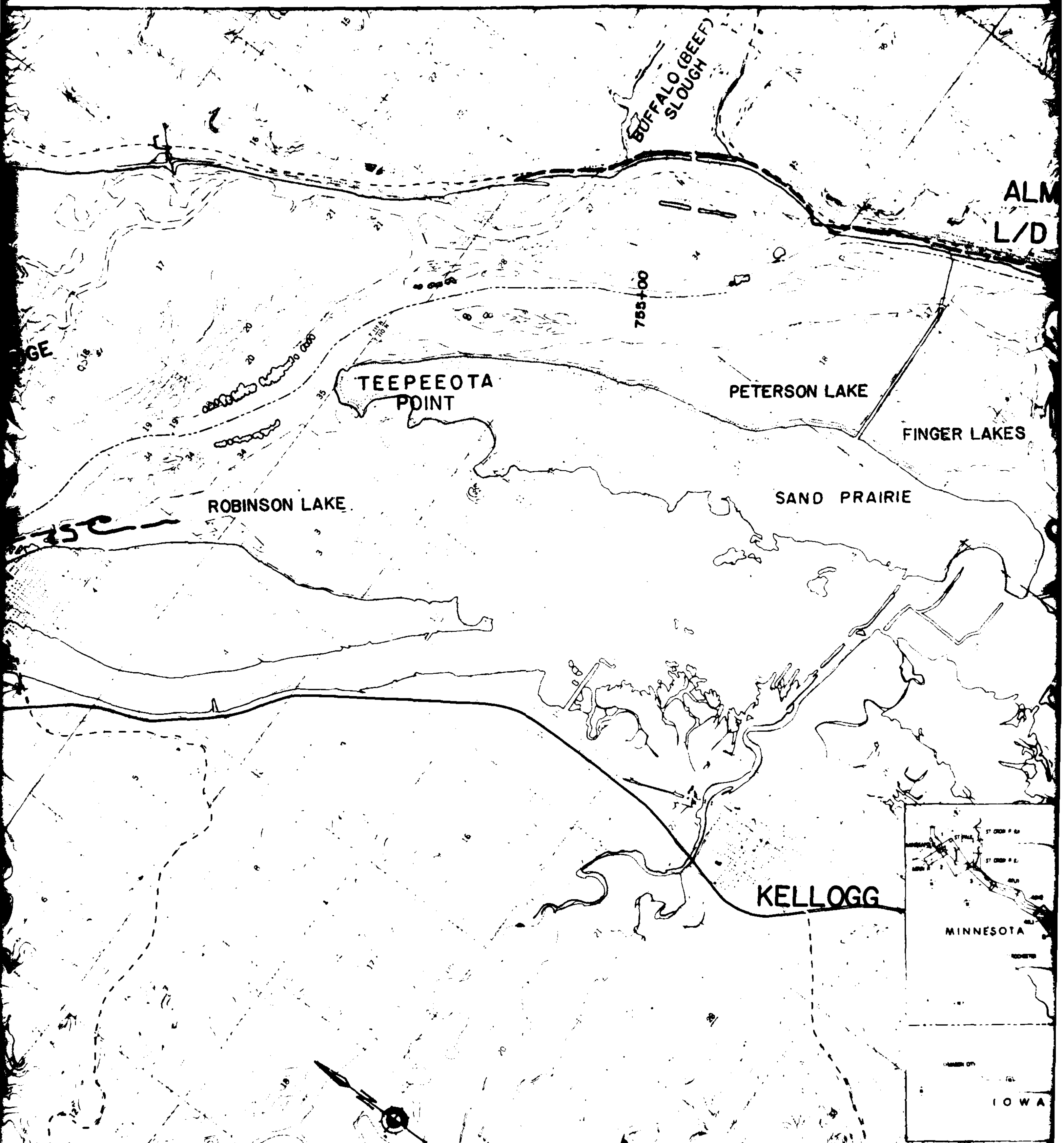

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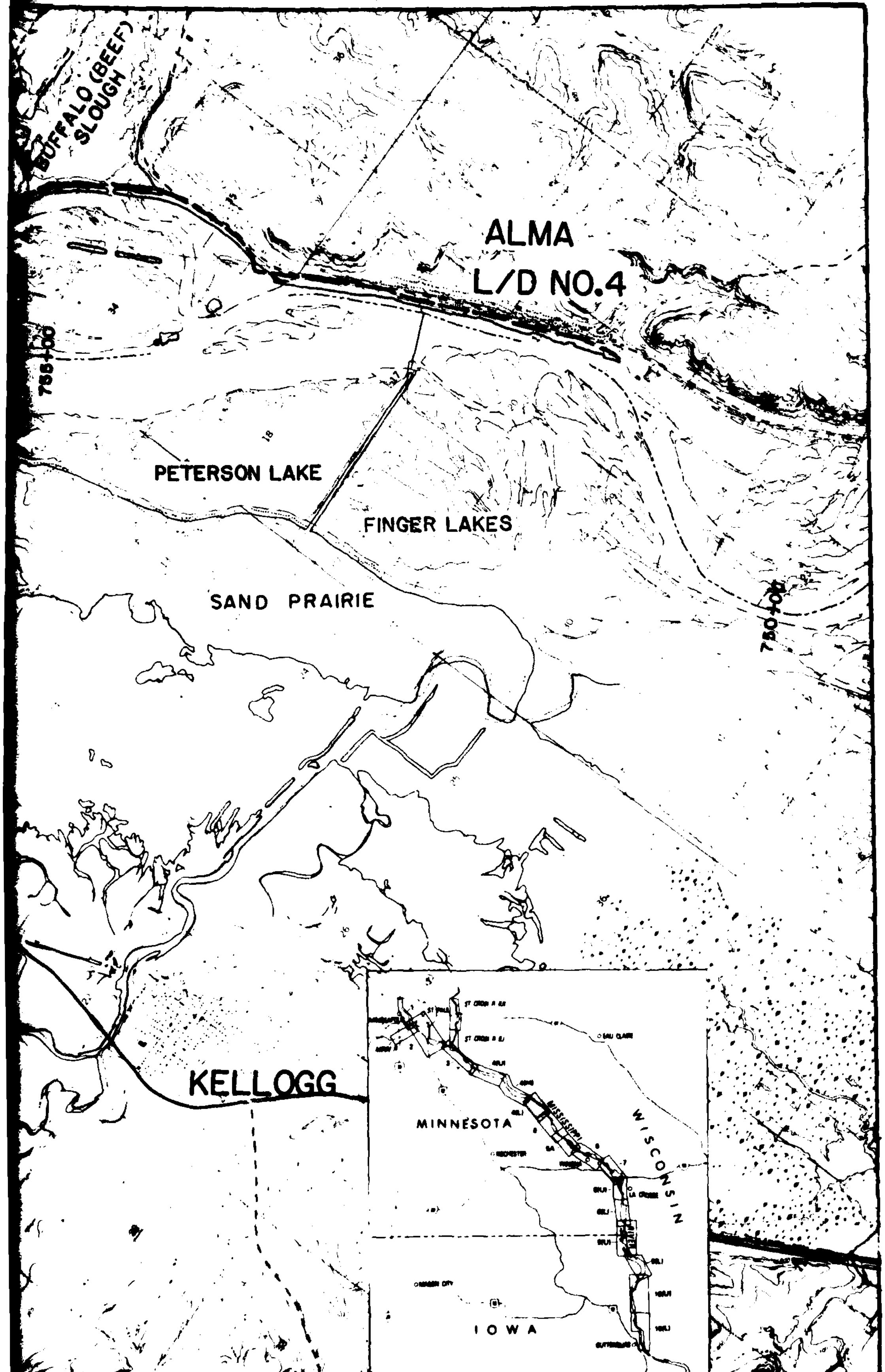

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(POOL 4(L)-MILE 752 TO MILE 766)

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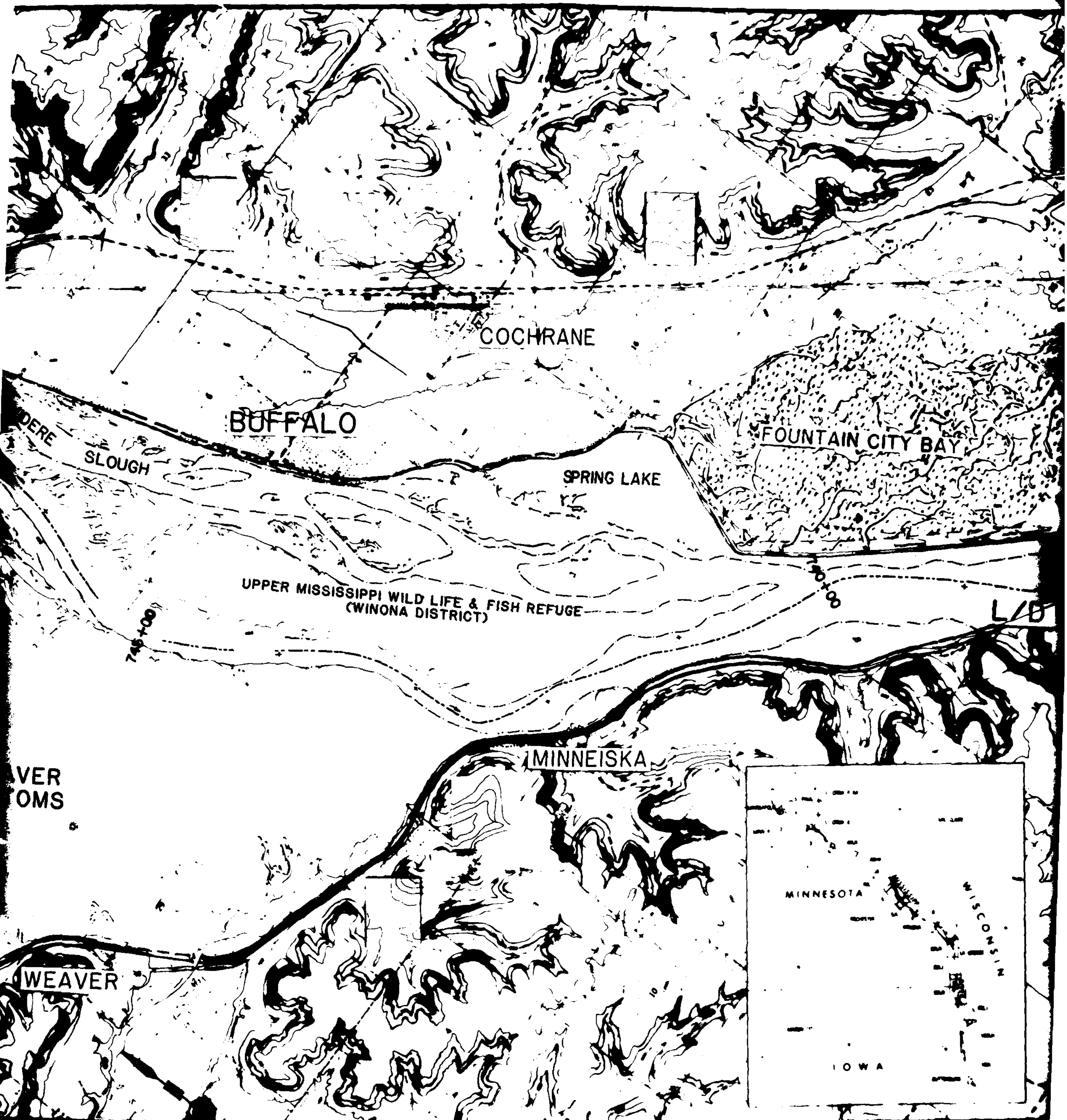

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UPPER MISSISSIPPI RIVER
(POOL 5 — MILE 738 TO MILE 753)

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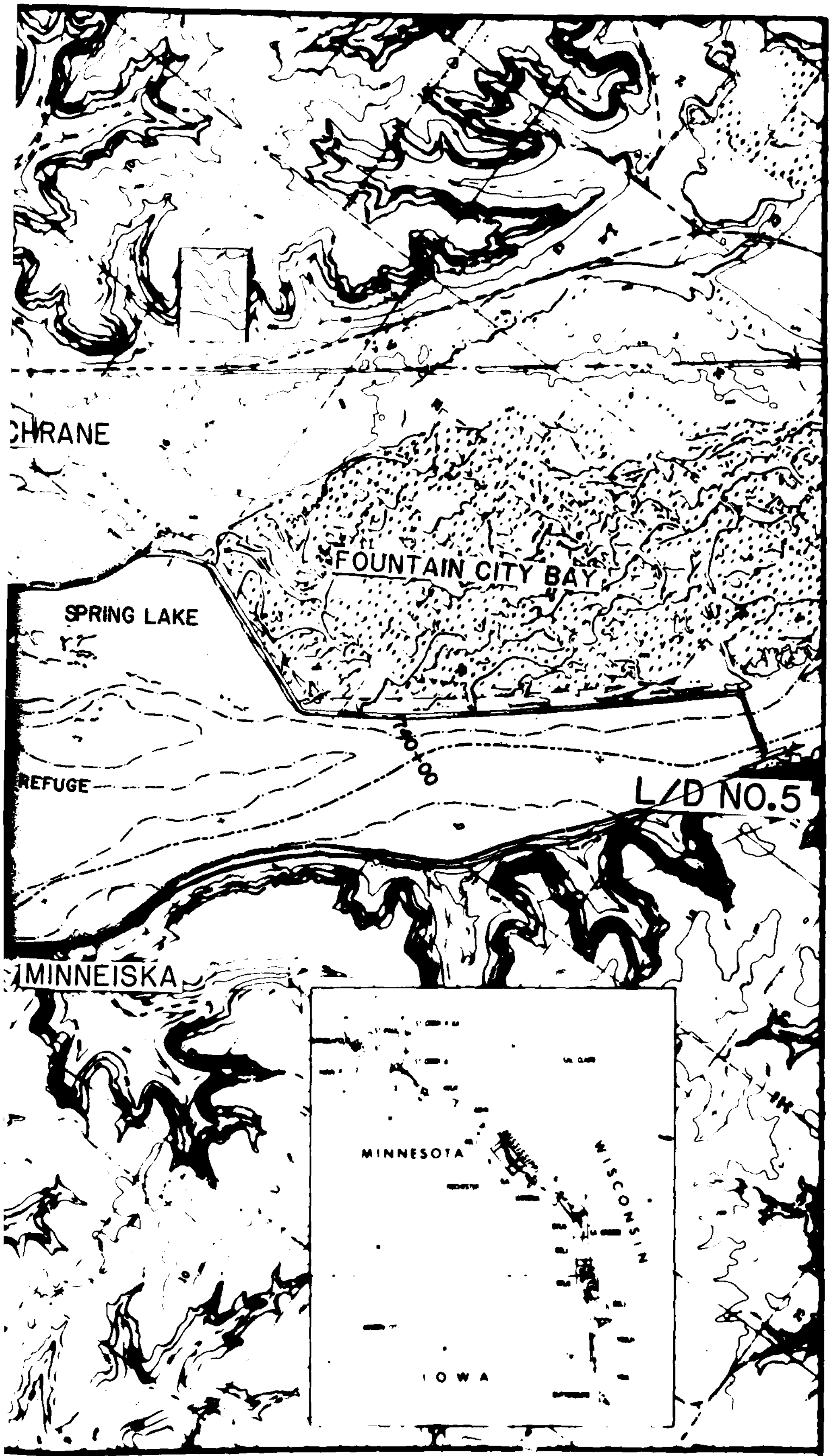

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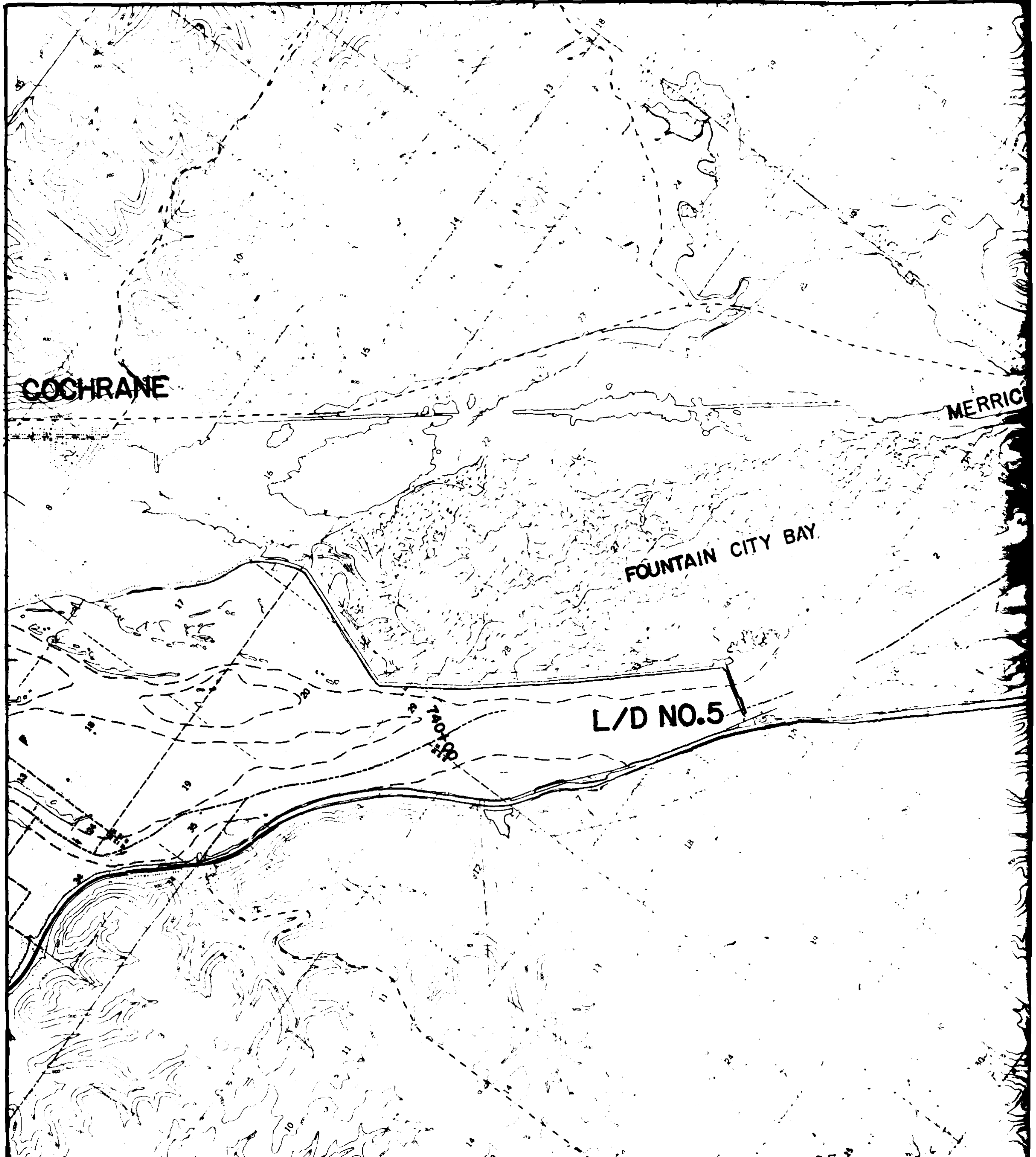
UPPER MISSISSIPPI RIVER
(POOL 5 — MILE 738 TO MILE 753)



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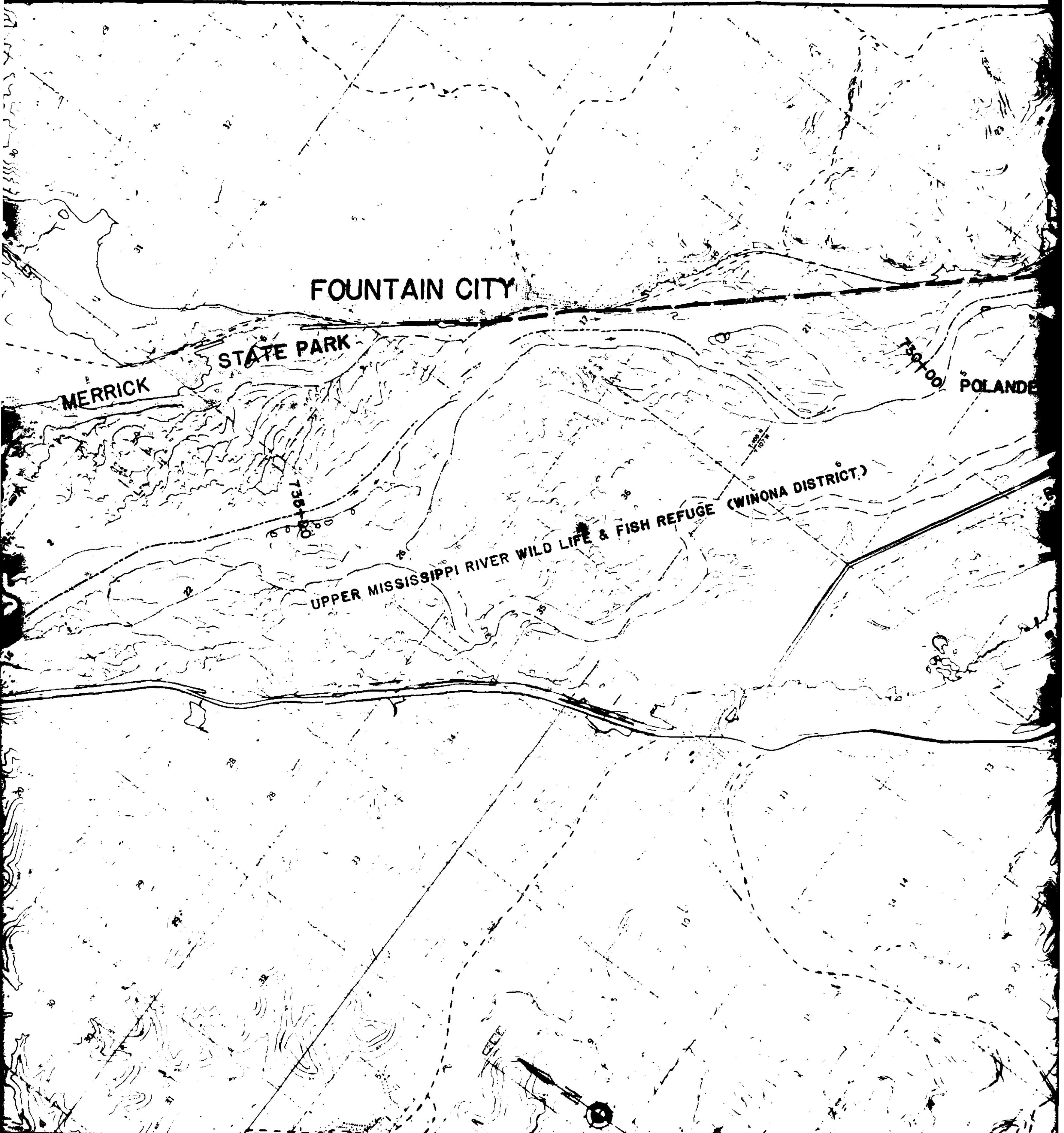

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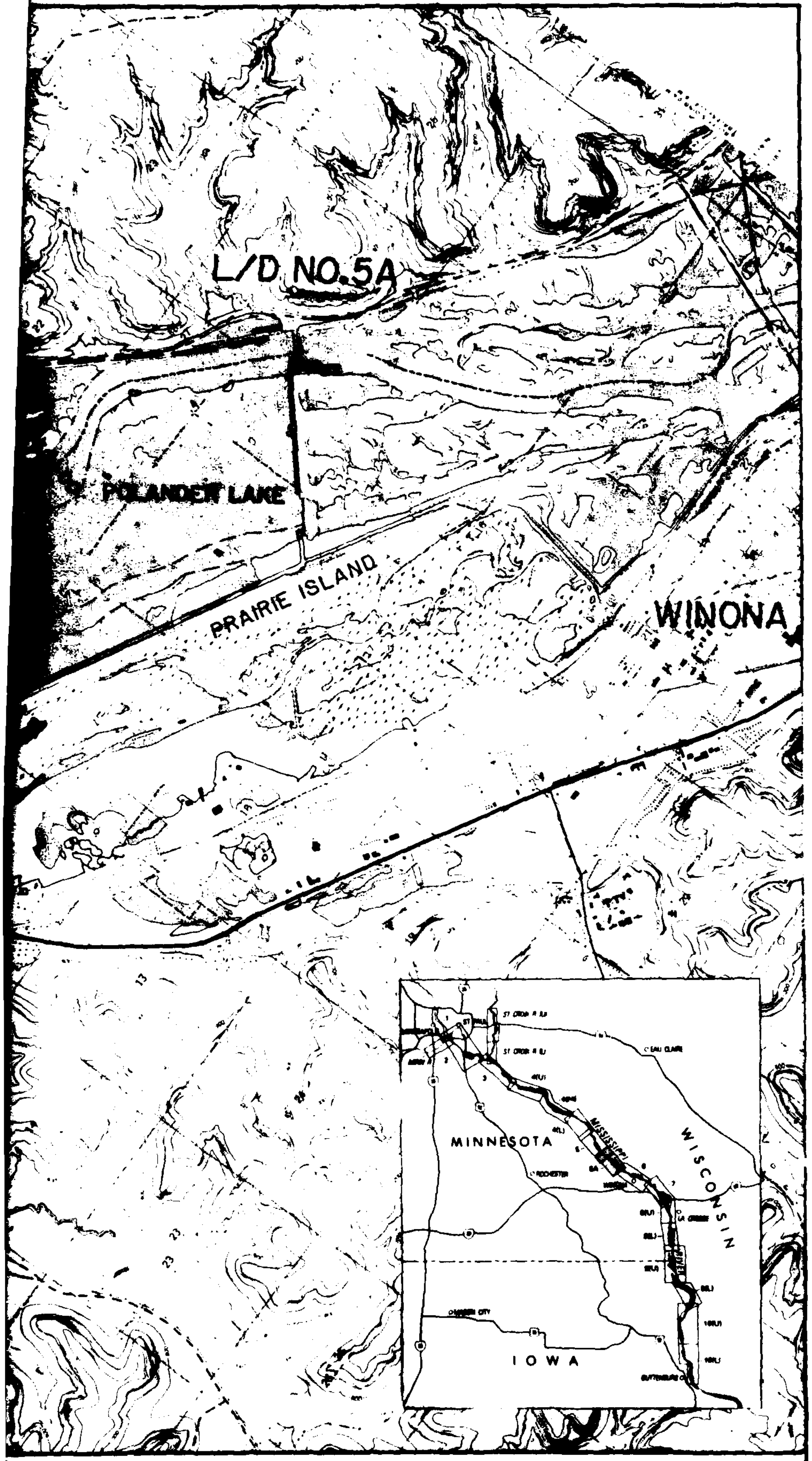

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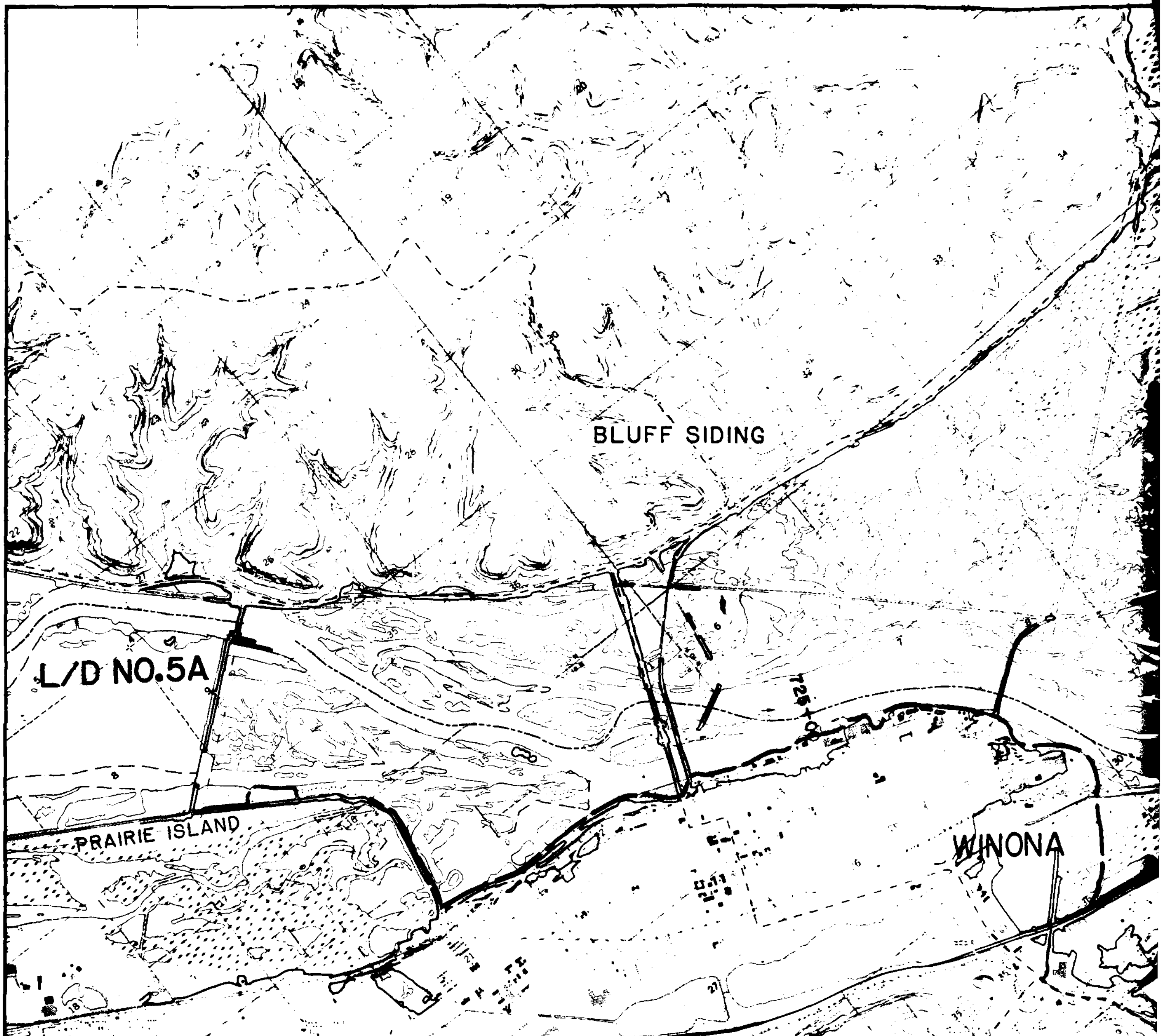
UPPER MISSISSIPPI RIVER
(POOL 5A-MILE 728 TO MILE 742)



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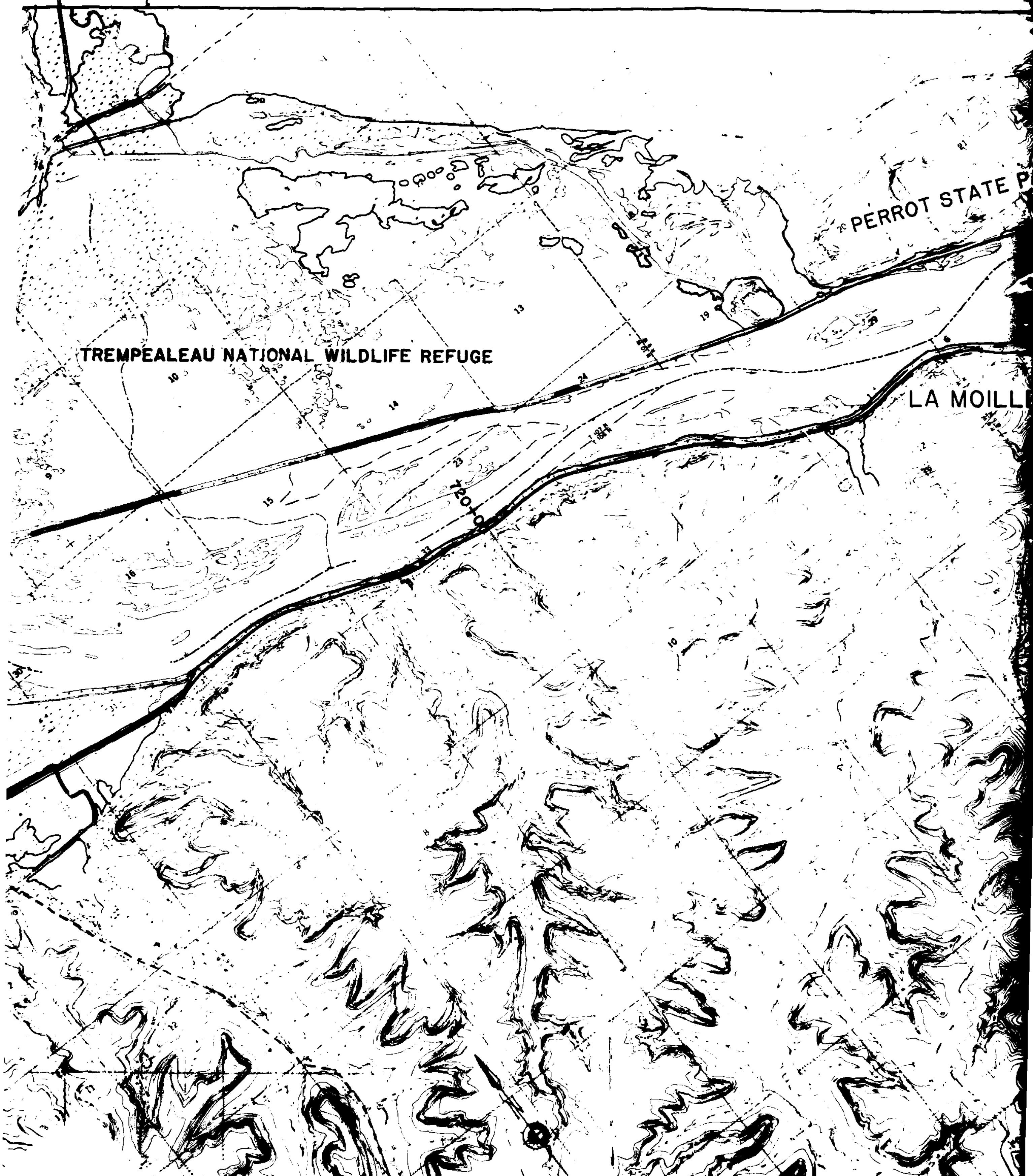

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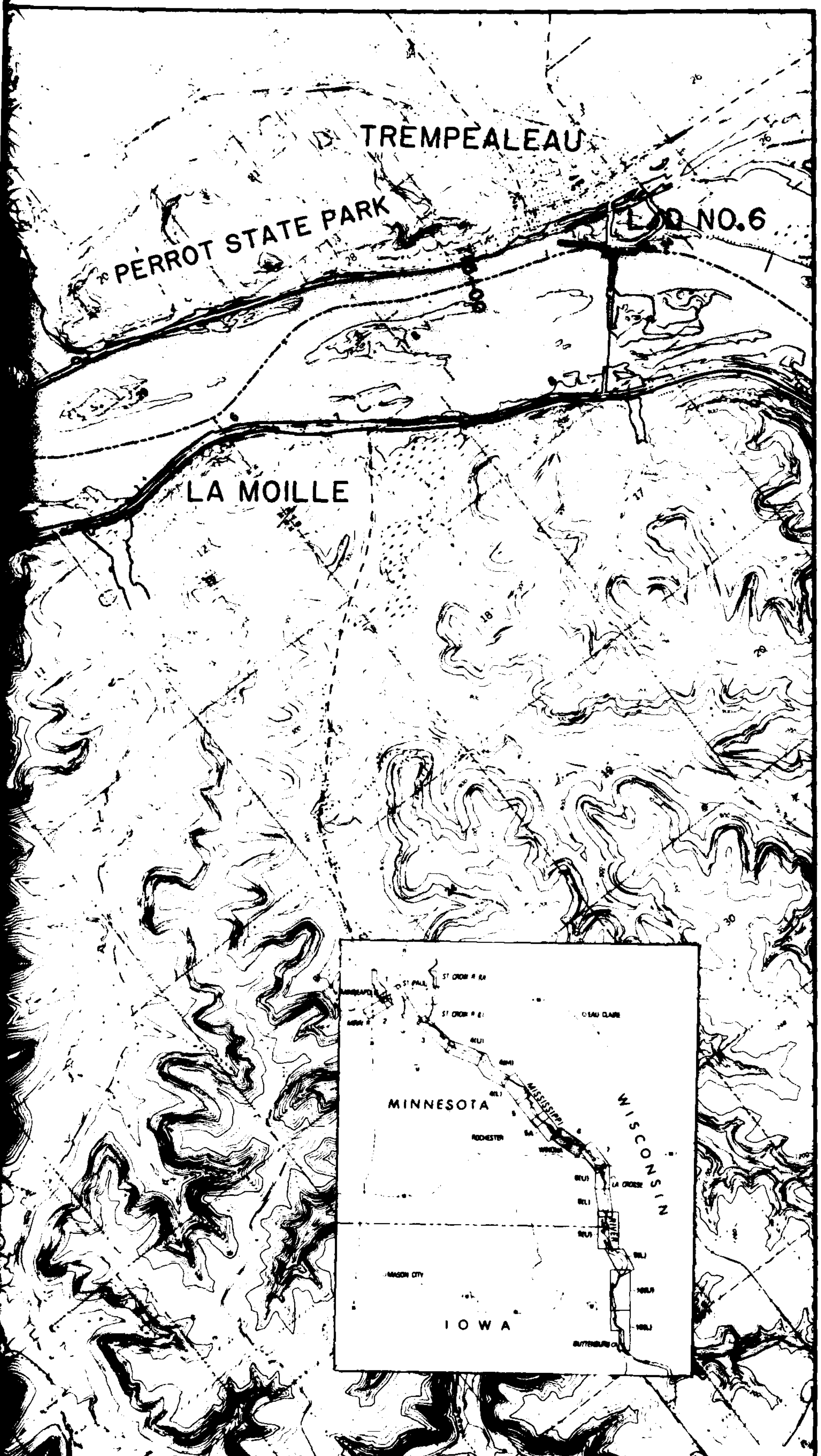

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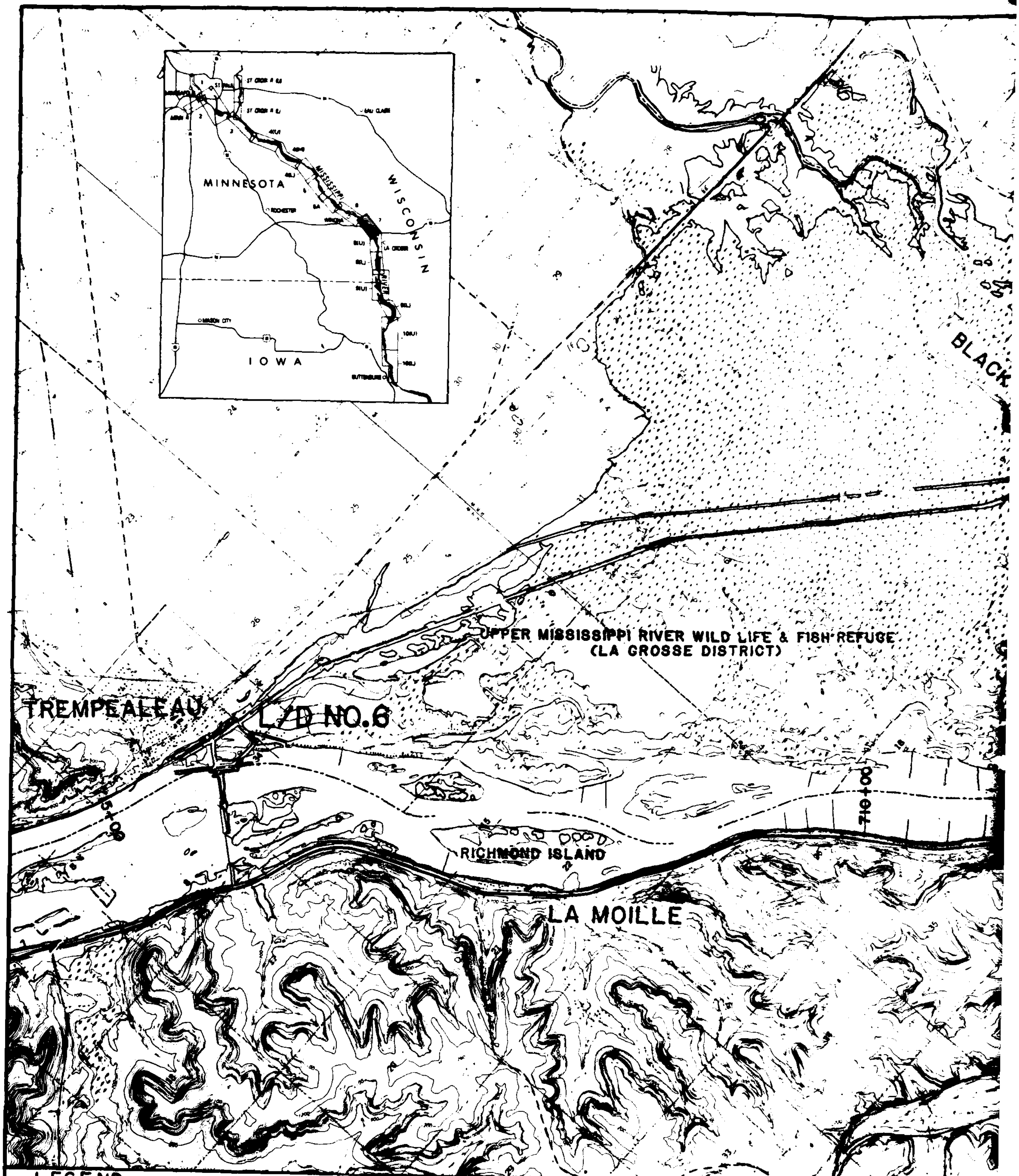
UPPER MISSISSIPPI RIVER
(POOL 6–MILE 714 TO MILE 729)



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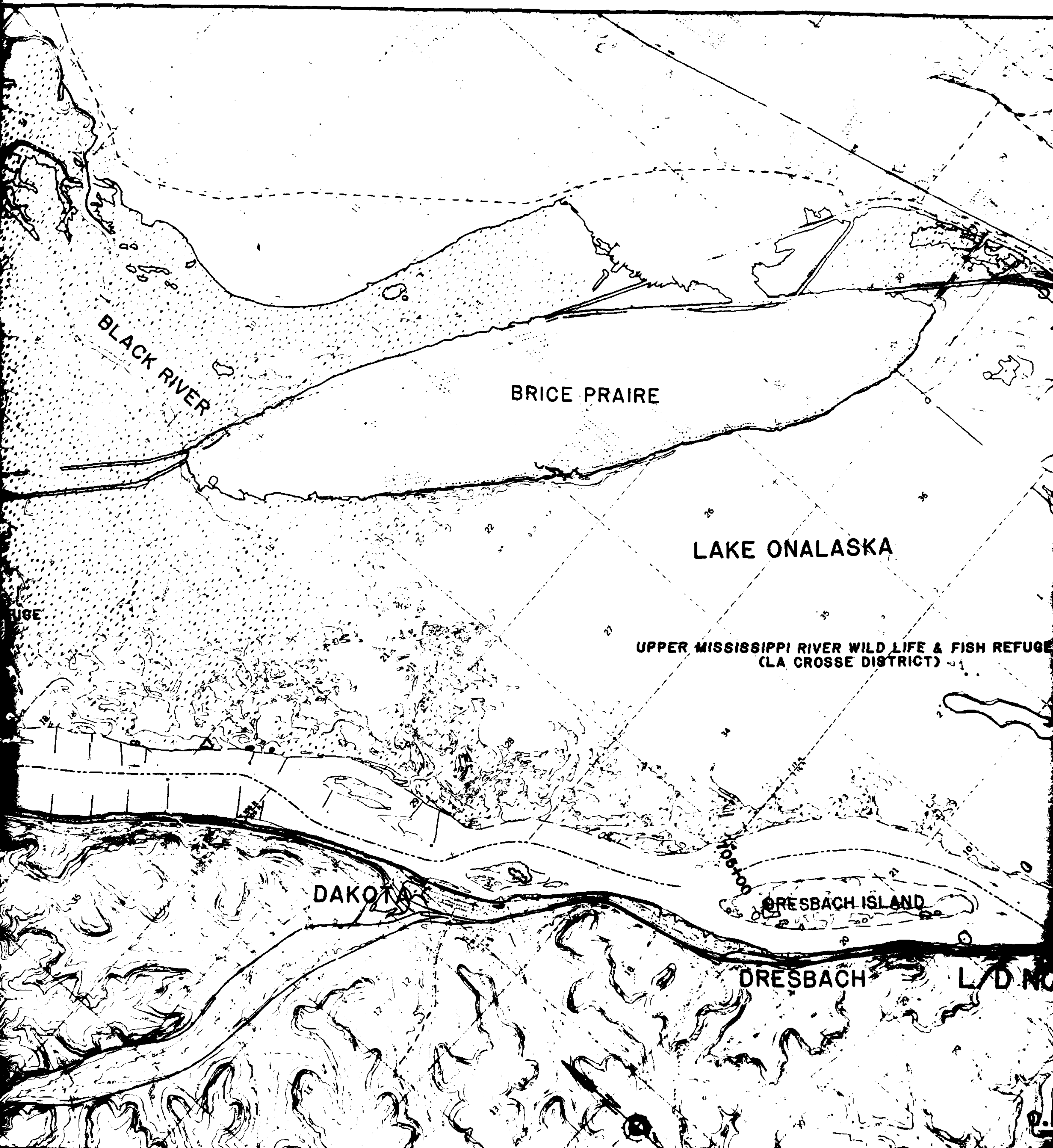

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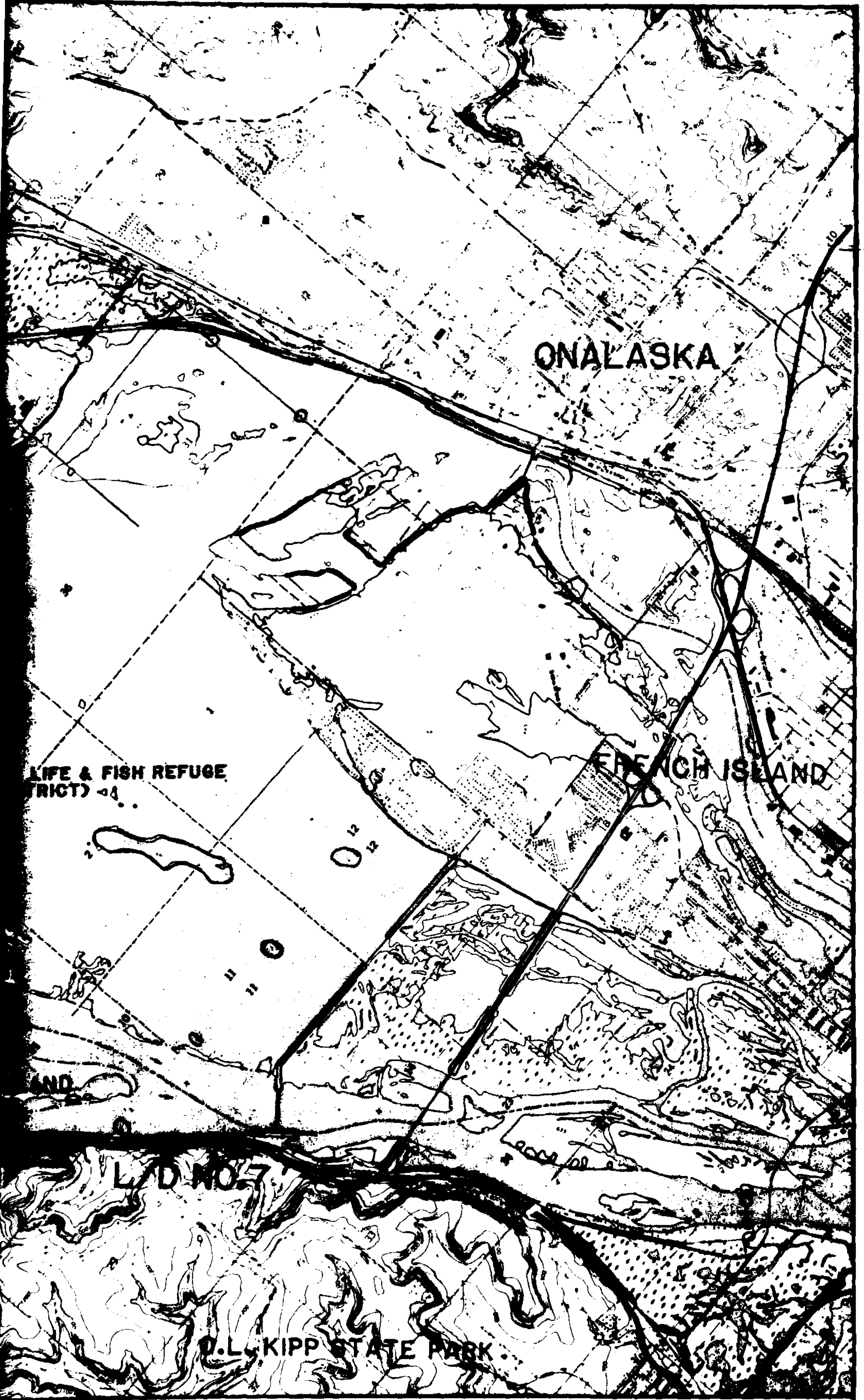

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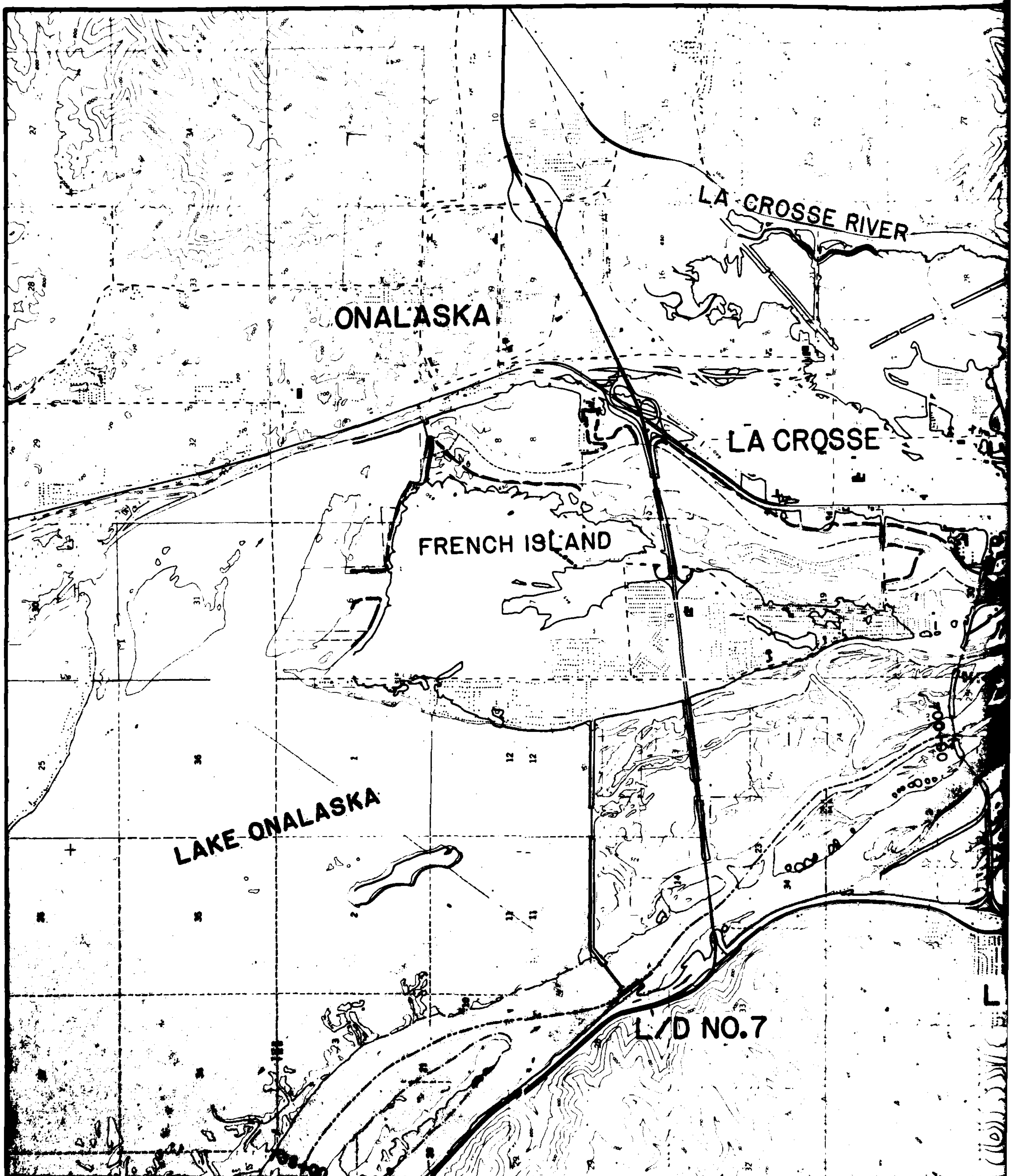
UPPER MISSISSIPPI RIVER

(POOL 7-MILE 701 TO MILE 714)



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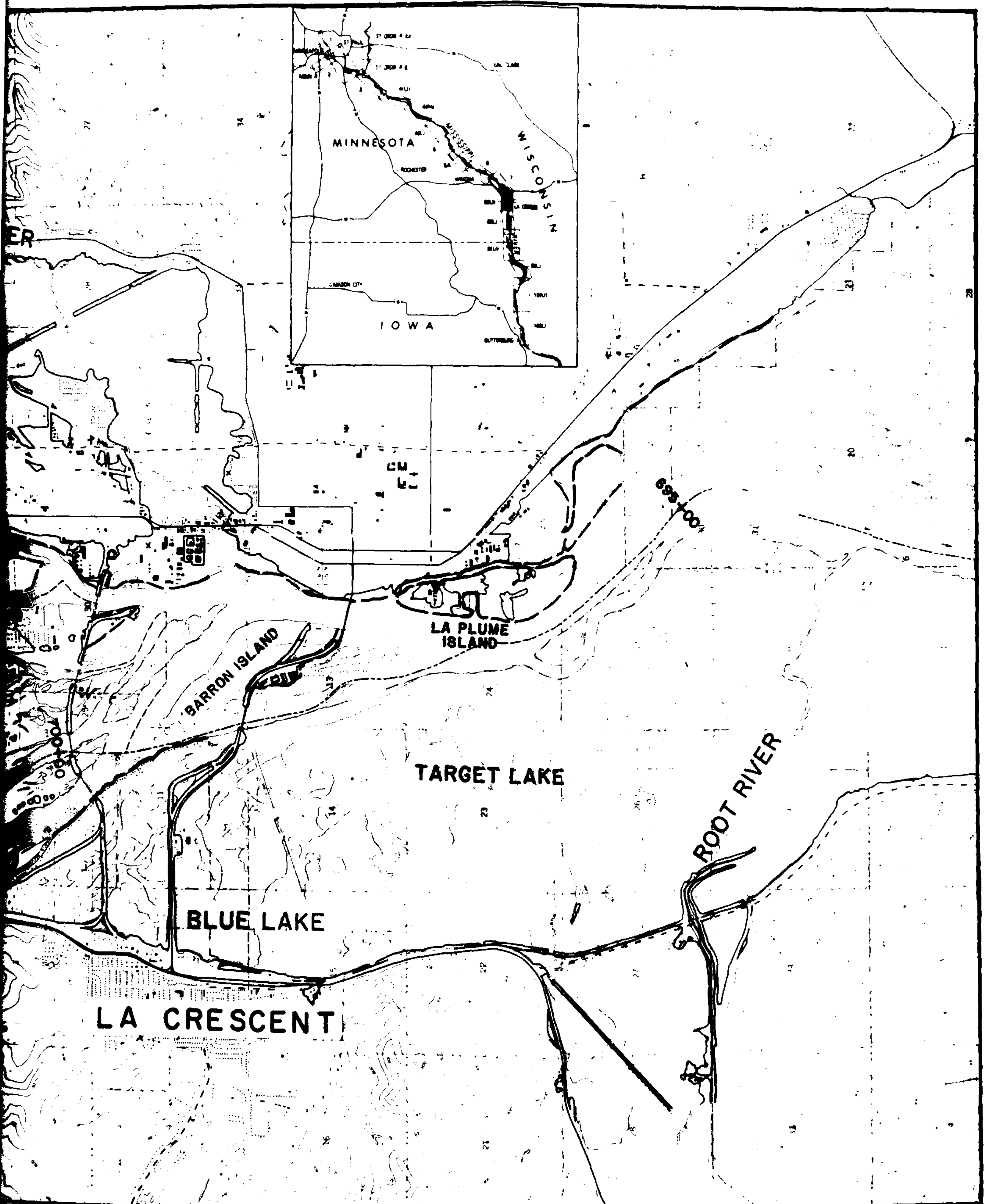

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(POOL 8(U)-MILE 693 TO MILE 704)

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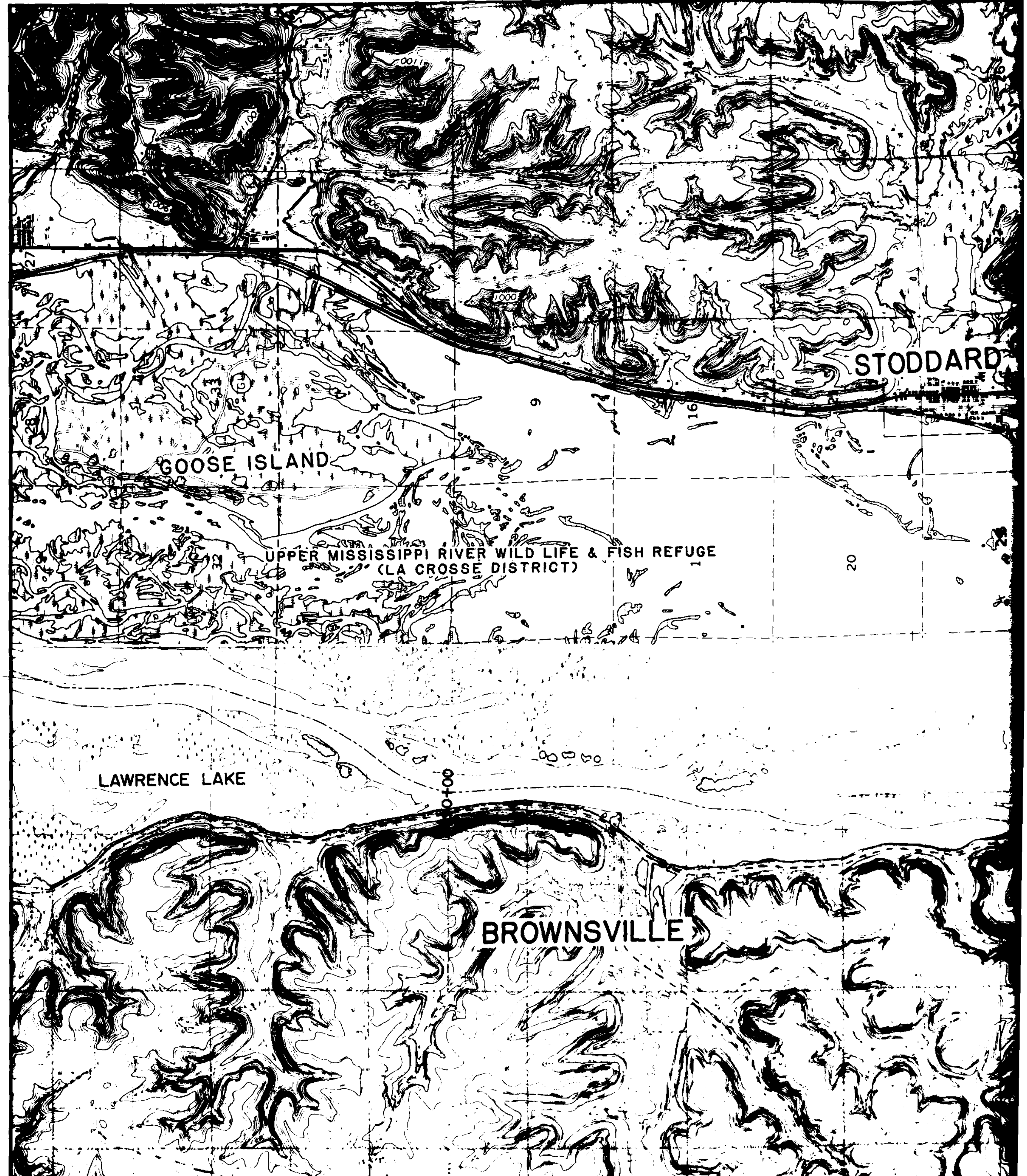

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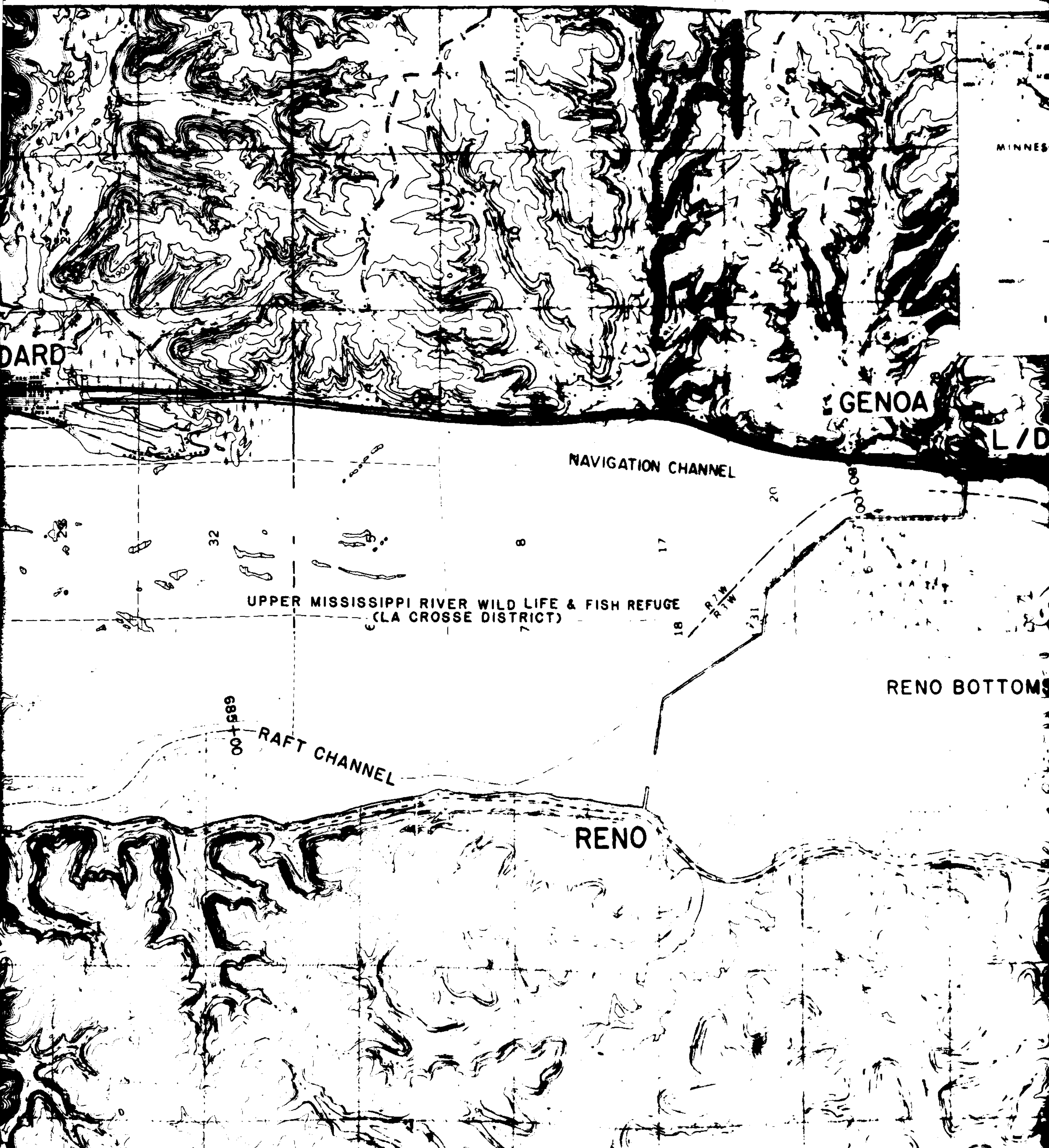

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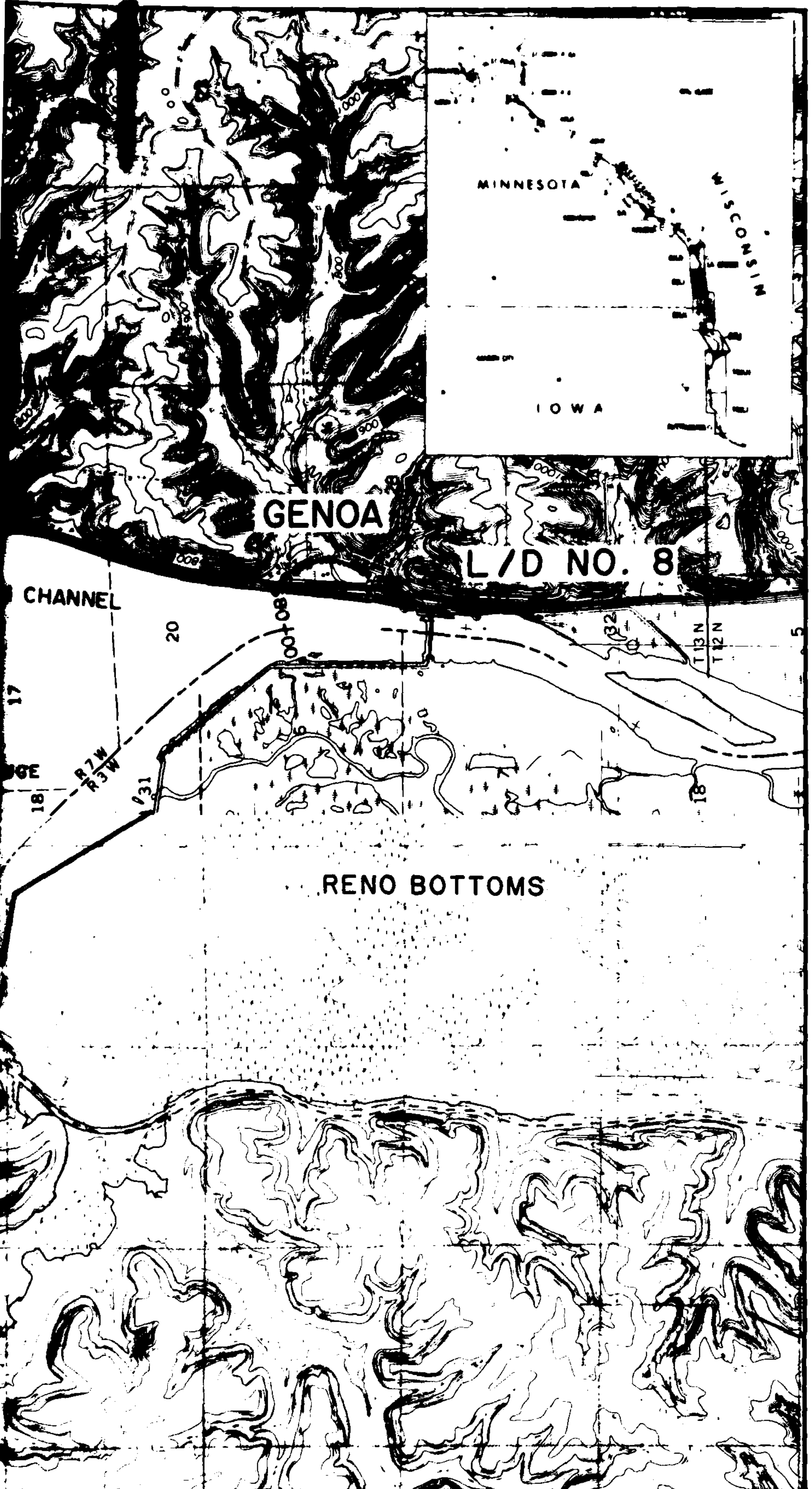

T RIVER ENVIRONMENTAL ACTION TEAM
UPPER MISSISSIPPI RIVER
(POOL 8(L)-MILE 679 TO MILE 692)

3


GENOA
L/D NO.8
RENO BOTTOMS
RENO
UPPER MISSISSIPPI RIVER WILD LIFE & FISH REFUGE
(LANSING DISTRICT)
LEGEND
— LIMIT OF APRIL 1965 FLOOD
- - - FLOODWAY DESIGNATED BY LOCAL ORDANACE

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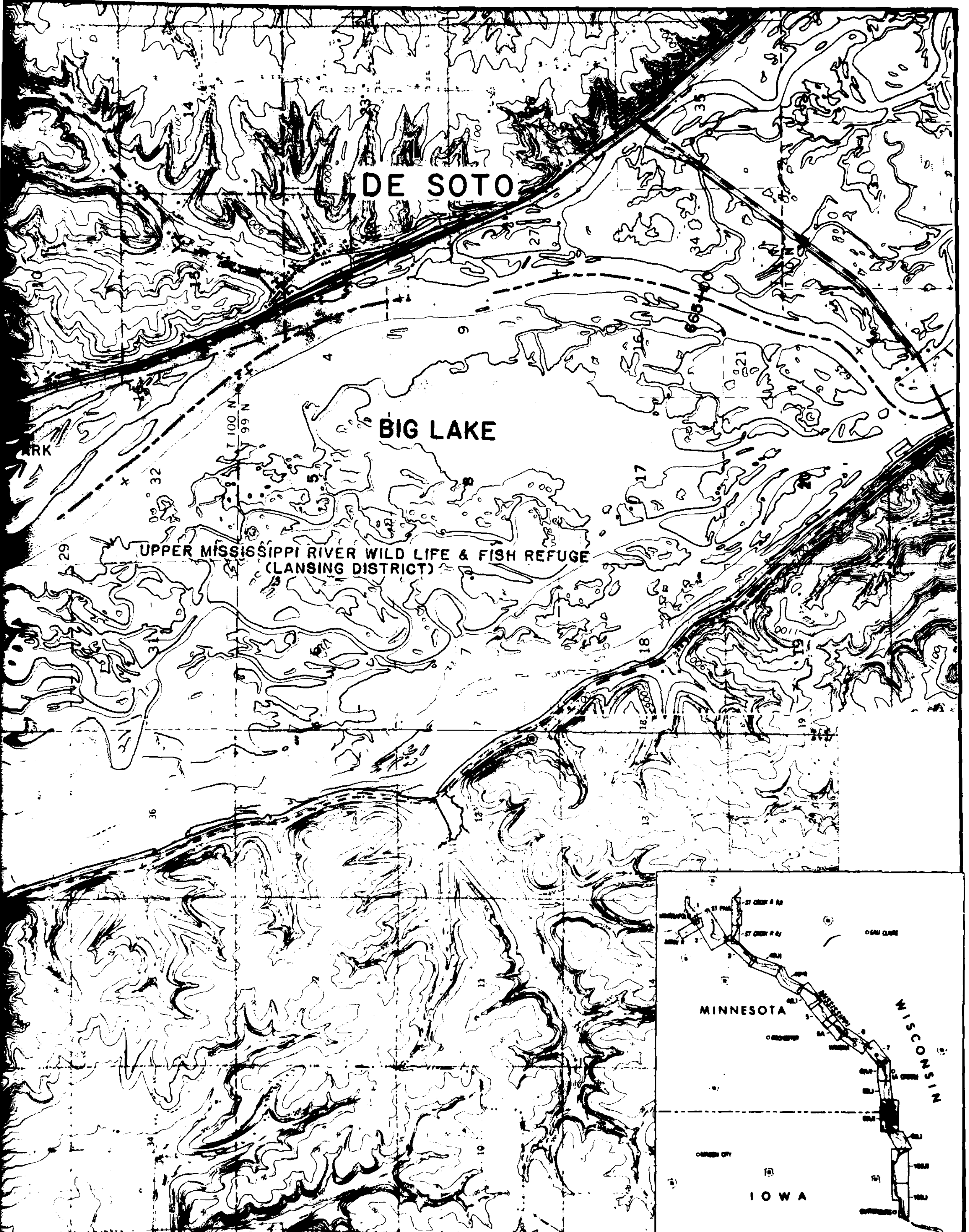
GENOA
NATIONAL FISH
HATCHERY
VICTORY
BATTLE ISLAND PARK
(COE)
BATTLE ISLAND
UPPER MIS
MINNESOTA
IOWA
MINNESOTA SLOUGH
UPPER IOWA RIVER
NEW ALBIN
GR

2



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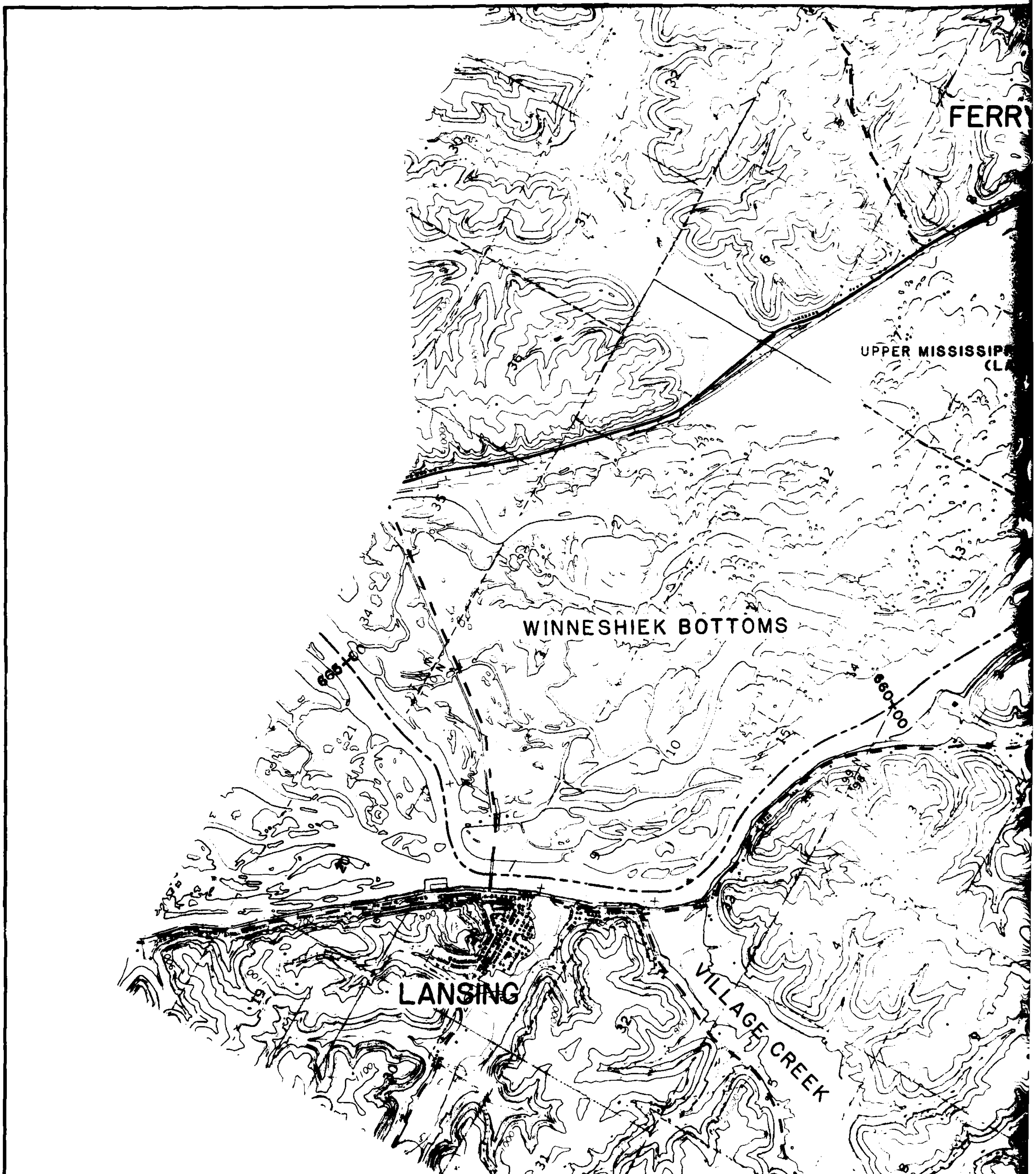
(POOL 9(U)-MILE 665 TO MILE 681)



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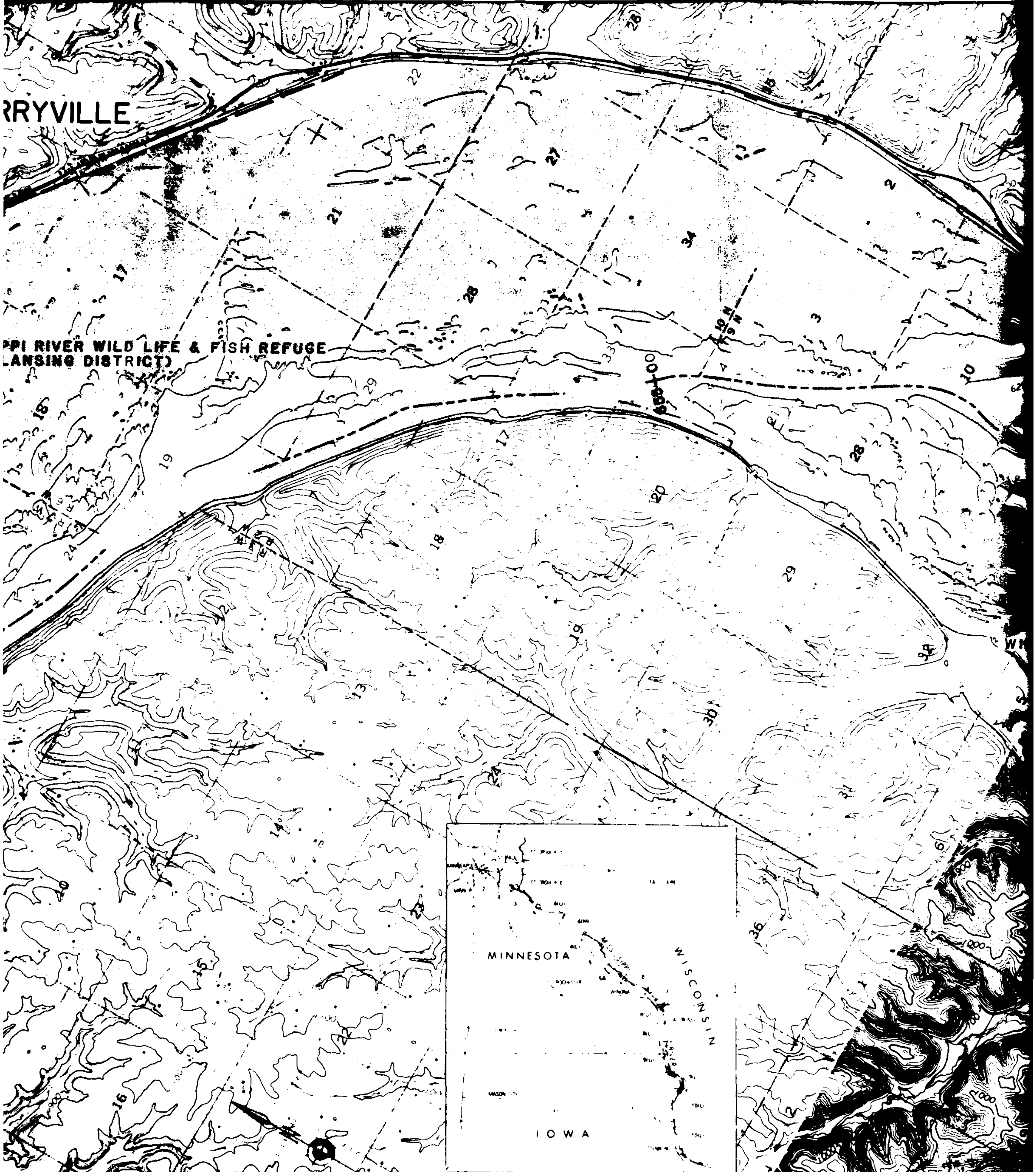

GREAT RIVER ENV

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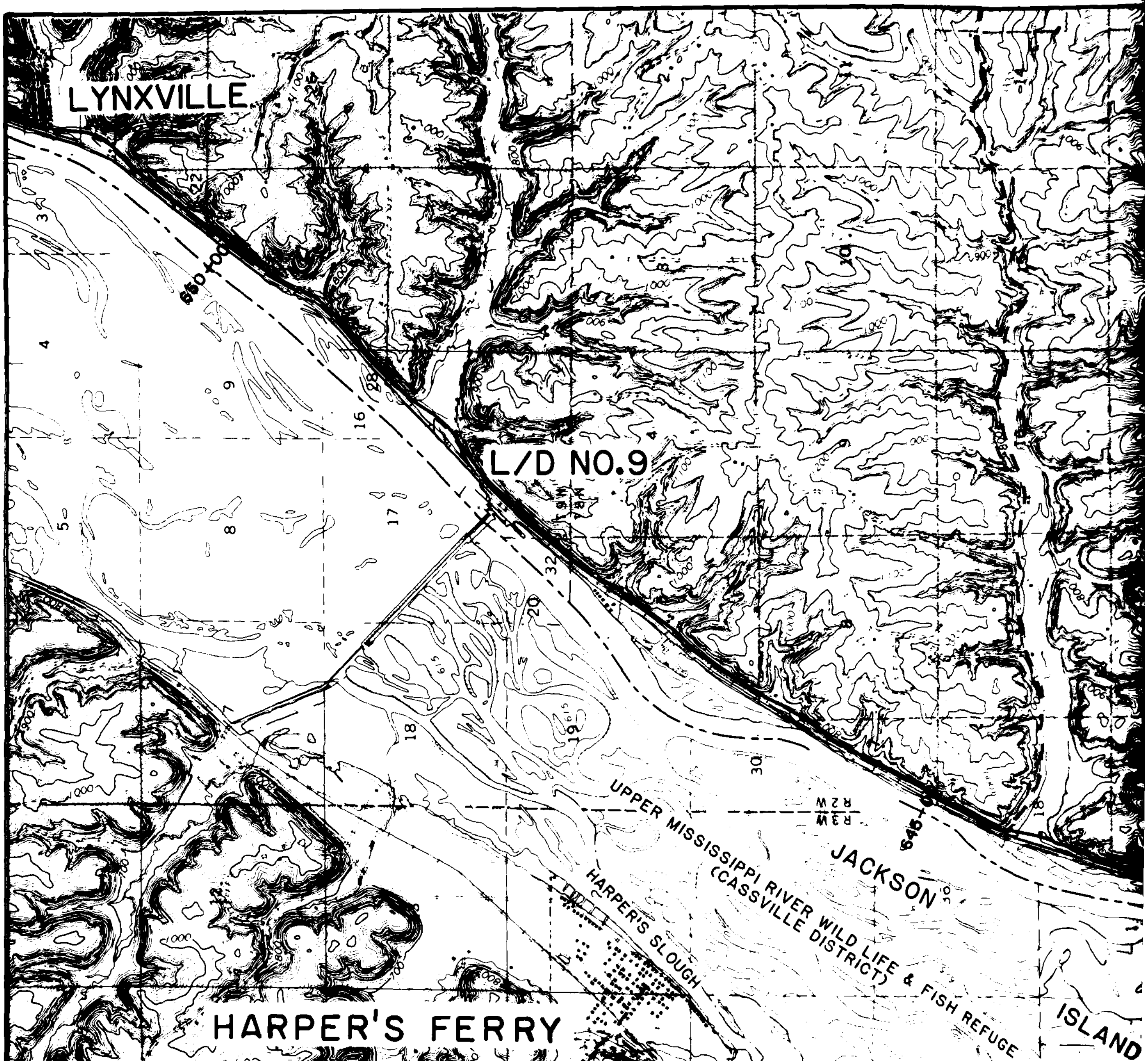
GREAT RIVER ENVIRONMENTAL ACTION TEAM
UPPER MISSISSIPPI RIVER
(POOL 9(L)-MILE 647 TO MILE 664)



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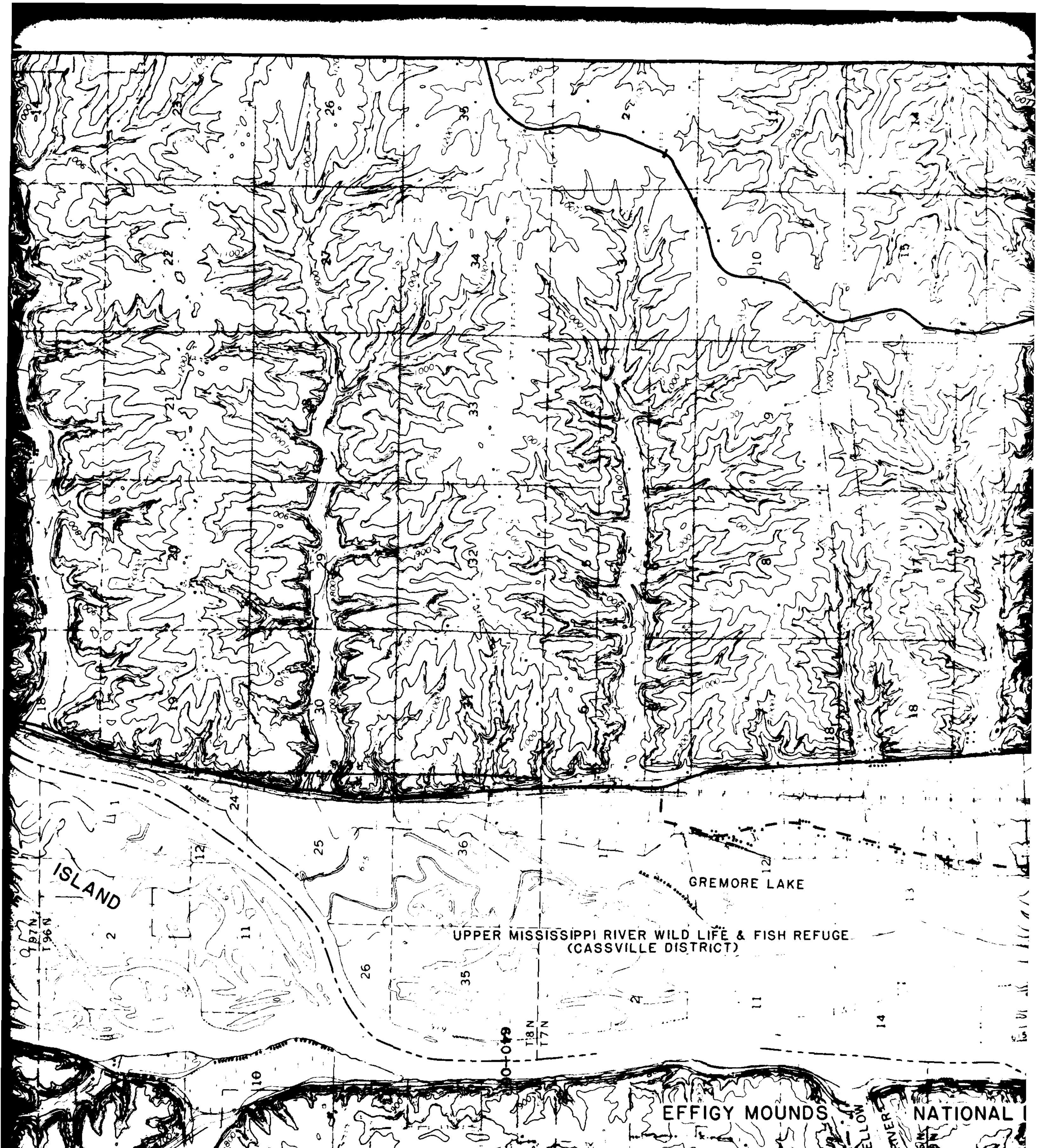
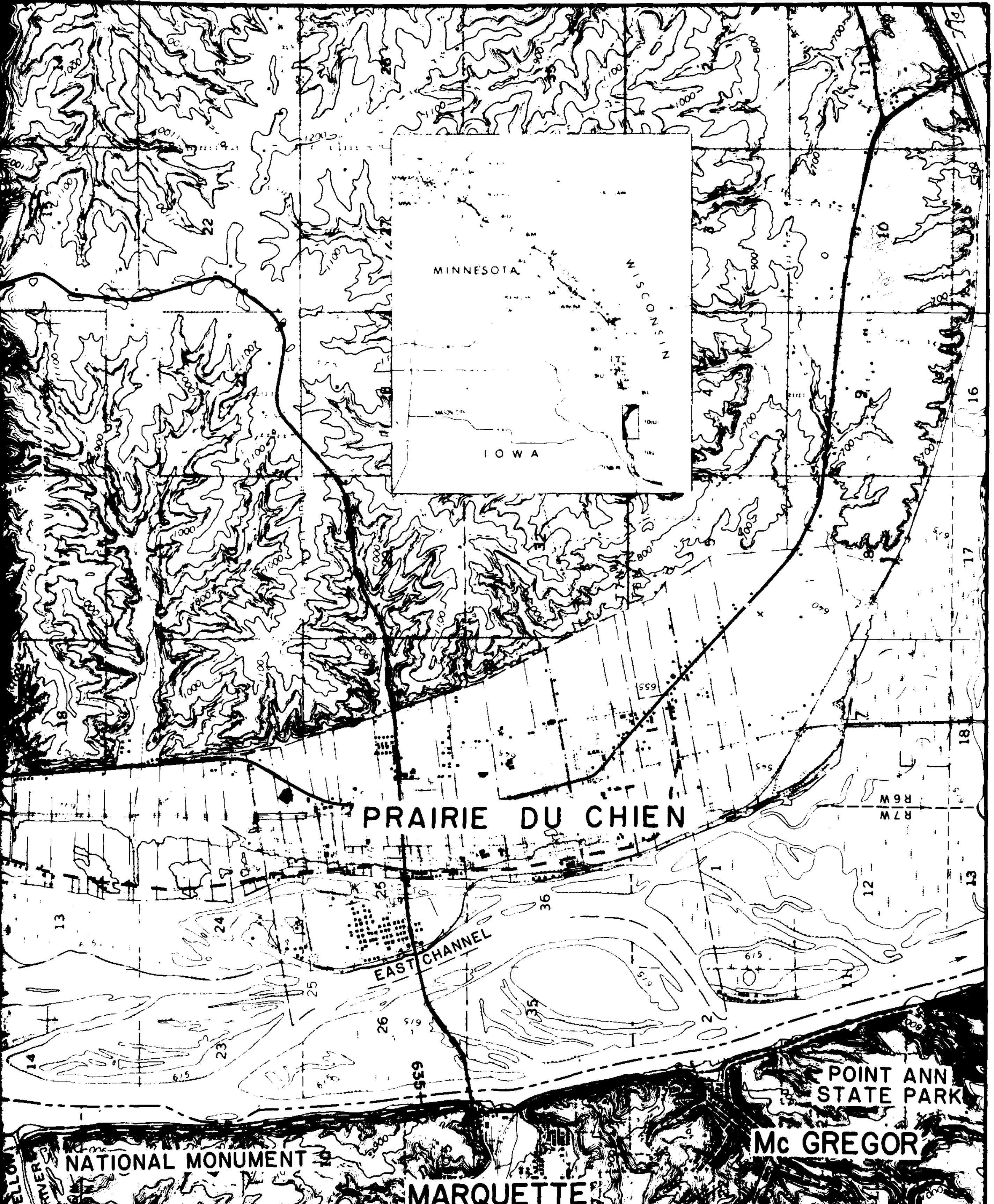


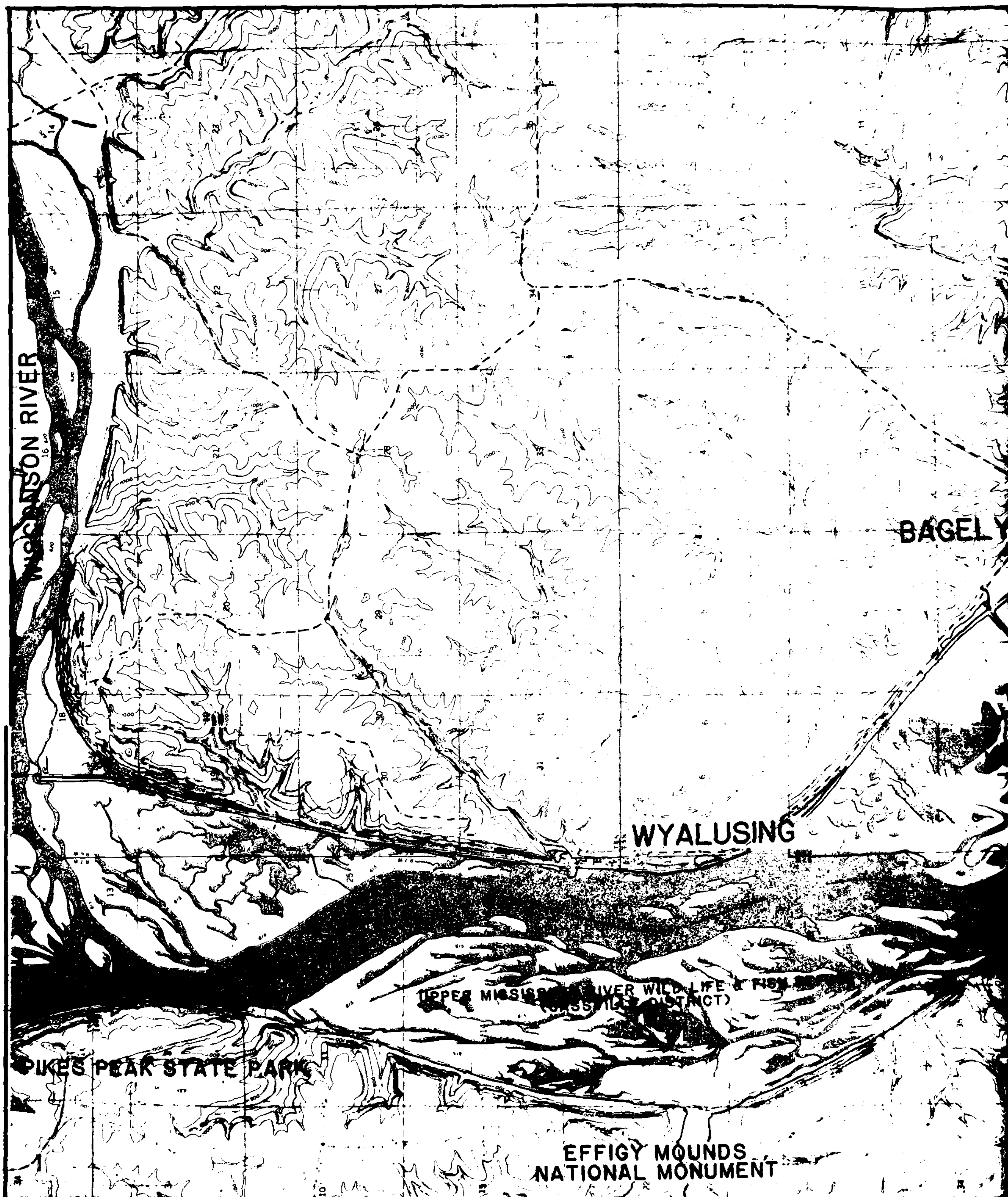
ISLAND
GREMORE LAKE
UPPER MISSISSIPPI RIVER WILD LIFE & FISH REFUGE
(CASSVILLE DISTRICT)
EFFIGY MOUNDS
NATIONAL
YELLOW
RIVER



GREAT RIVER ENVIRONMENTAL ACTION TEAM

UPPER MISSISSIPPI RIVER

(POOL 10(U)-MILE 632 TO MILE 651)



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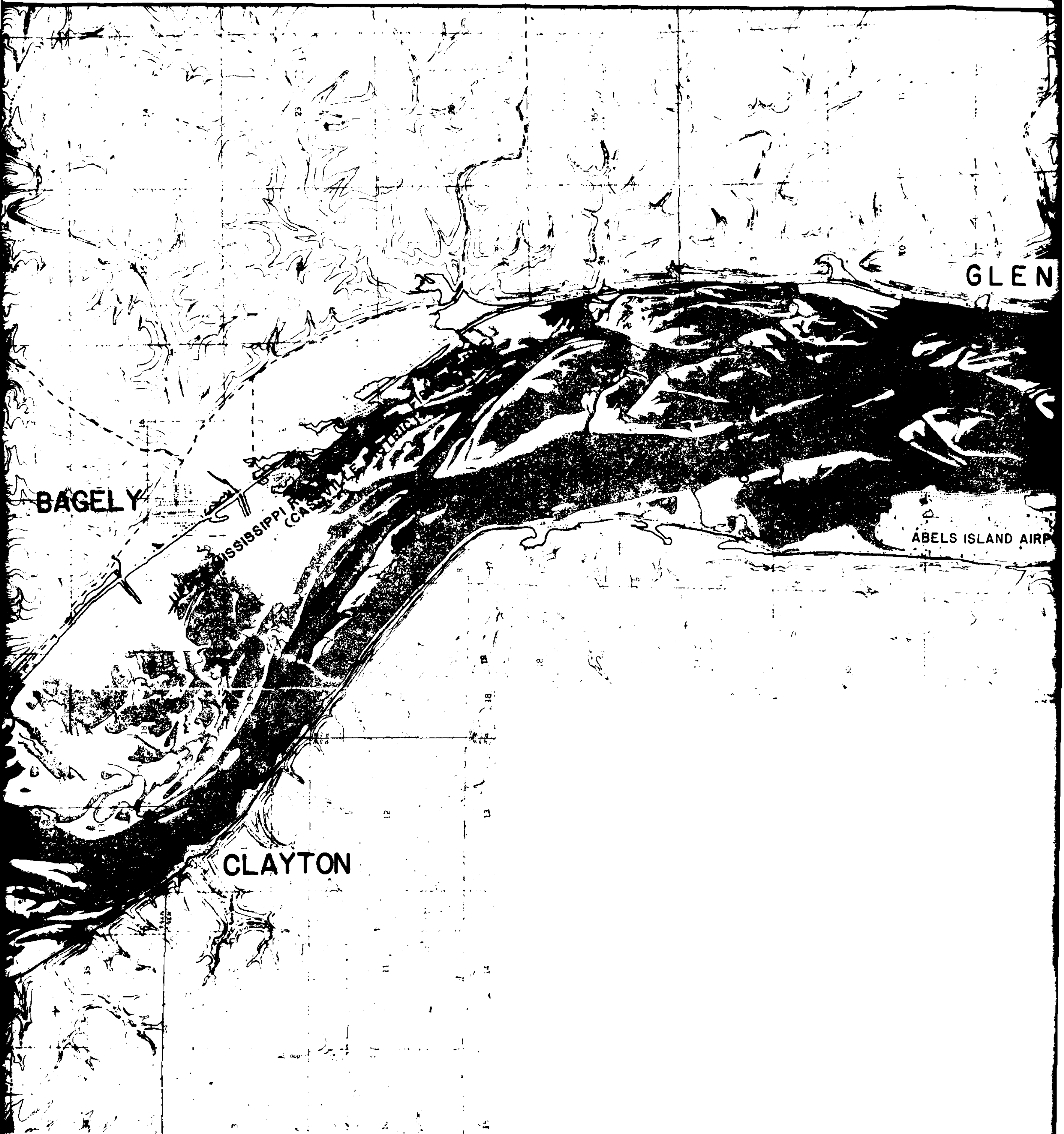

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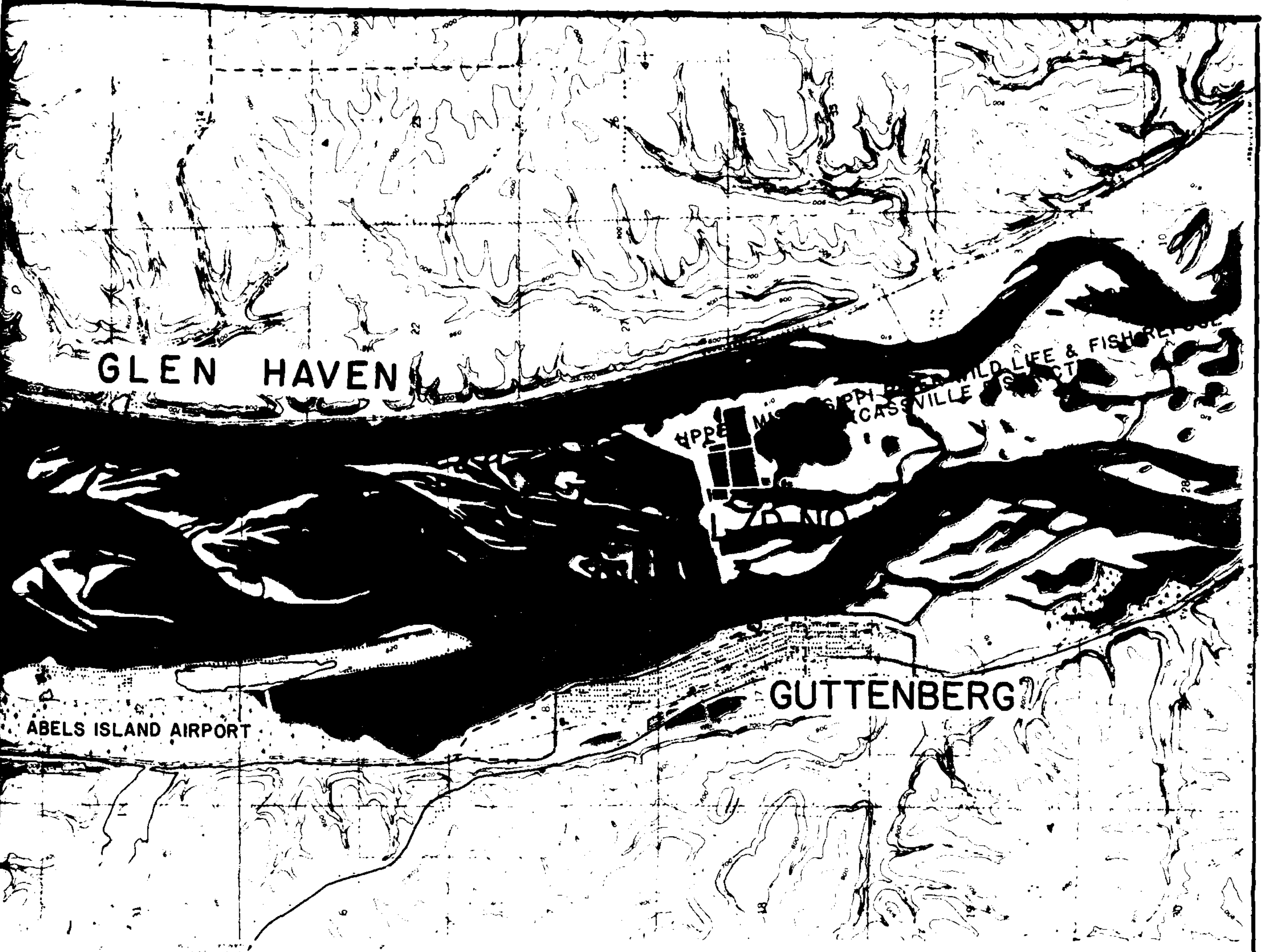

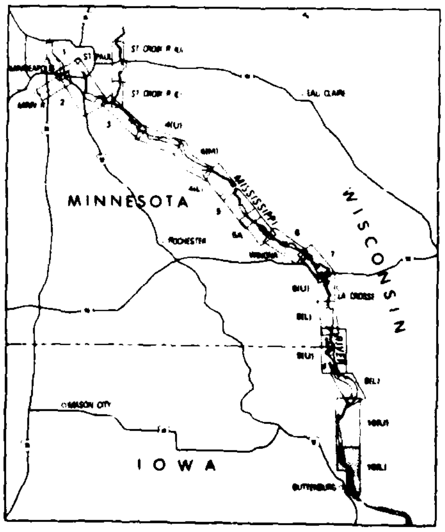

GREAT RIVER ENVIRONMENTAL ACTION TEAM
UPPER MISSISSIPPI RIVER
(POOL 10(L)-MILE 613 TO MILE 631)

3

B. DREDGED MATERIAL USES

FINAL
DREDGED MATERIAL USES WORK GROUP
APPENDIX
TO
FINAL REPORT
OF
GREAT RIVER ENVIRONMENTAL ACTION TEAM
(GREAT I)

Thomas A. Lovejoy, Chairman (1979-80)

Scot J. Ironside, Chairman (1977-79)

Mark A. Riebau, Chairman (1975-77)

written by

S. Ironside, M. Riebau, J. Clark, T. Lovejoy and D. Kennedy

Wisconsin Department of Natural Resources

3550 Mormon Coulee

La Crosse, Wisconsin 54601

Under Contract No.
DACW 37-75-C-0195

TO

U.S. Army, Corps of Engineers
St. Paul District
1135 U.S. Post Office and Custom House
St. Paul, Minnesota 55101

FOREWORD FROM THE GREAT TEAM

This report was prepared by the Dredged Material Uses Work Group of the Great River Environmental Action Team (GREAT I). The conclusions and recommendations presented reflect the work performed by this work group only, within its specific area of expertise. Recommendations from this report will be considered in relation to other objectives for overall resource management and may be included in the final GREAT I report as considered appropriate by the GREAT I Team.

ACKNOWLEDGMENTS

Many individuals from various State and Federal agencies assisted throughout the study. The Dredged Material Uses Work Group provided the multiagency input essential to the balanced research effort.

The expertise of Larry Larson, Mark Riebau, David Kennedy, Wendy (Thur) Nichols, and many other Wisconsin Department of Natural Resources staff and Charles Anderson and H. E. Gundlach of the Wisconsin Department of Transportation provided clear direction and critical insights to the chairman.

Christiane Witzke, William Hanson, Michael Nicosia, Terry Marx, and JayNe Johnson provided vital assistance in carrying out the work group's duties.

Critical reviews by Fred Dorheim, Mark Ackleson, and especially Gordon Slifer were extremely helpful.

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I. INTRODUCTION

Sediment related problems are a major concern in the St. Paul District's 242.5 miles of the Upper Mississippi River. Sediment deposition within the navigation channel necessitates annual historic dredging of over 1.8 million cubic yards within the District (Minneapolis, Minnesota, to Guttenberg, Iowa, GREAT I study area) (U.S. Army Corps of Engineers, 1974).

Channel maintenance dredging has high monetary, social, and environmental costs. Dredging operations often cause turbidity, re-suspension of contaminants, and isolation of backwaters. Dredged material placement has caused and continues to cause the destruction of valuable wetland habitat. Over 2,300 acres of sand islands have been created in the middle of the Upper Mississippi River the past 40 years. In creating these islands, valuable terrestrial and aquatic habitat has often been buried.

II. SUMMARY OF CONCLUSIONS

The Dredged Material Uses Work Group (DMUWG) came to the following conclusions as a result of research and many hours of discussion with people of the river valley.

1. Dredged material is a valuable resource.

2. There is a large demand for dredged material.

3. Dredged material can be made available in most reaches of the GREAT I study area.

4. Beneficial use of dredged material serves both the environmental and economic interests of the area.

5. Dredged material cannot, at this time, be used economically as a fine aggregate in concrete.

6. Dredged material can be used economically as a blending sand in asphalt.

7. Dredged material can be economically used for landfill.

8. Dredged material can be economically used for highway ice control.

9. The legal implications of providing dredged material free of charge to private enterprise are not known at this time.

10. Dredged material can be used for the construction of flood control levees.

III. SUMMARY OF RECOMMENDATIONS

The studies and surveys done have led the DMUWG to make the following recommendations:

1. Material dredged during normal channel maintenance should be placed where it can be available for beneficial use.

2. Permanent material stockpile sites should be established near population centers.

3. The Corps should request the necessary appropriations to purchase effective and efficient dredging equipment or contract with private firms. All State and Federal agencies should seek congressional support for this request.

4. A procedure should be developed to easily and quickly incorporate new sites for material placement as new demands appear.

5. The Corps should provide dredged material to users free of charge. When legal restraints prevent this, the material should be sold at its "fair market value" as determined by competitive bidding.

6. Research should be conducted to determine if structures could be installed along the sides of the channel that would cause sand to deposit at areas of continual high demand, such as population centers.

7. The economic feasibility of transporting sand from dredged material islands to areas of demand by private enterprise should be explored.

8. The economic feasibility of constructing railroad side tracks adjacent to chronic dredging areas so dredged material can be transported to areas of high demand should be examined.

9. An economic feasibility study should be made of constructing a permanent pipeline with booster pumps to transport dredged material from chronic dredging areas to areas of high demand.

10. Studies should be initiated to determine the potential beneficial uses of fine sediments. The studies should address the problems of contaminants and dewatering often associated with fine organic material.

11. The potential for making riprap using dredged material and cement should be studied.

12. An interagency organization, patterned after GREAT, should be established and given the authority to manage the Upper Mississippi River.

13. The Corps of Engineers should change its policies to allow acquisition of private lands for stockpiling of dredged material for beneficial use.

IV. DREDGED MATERIAL USES WORK GROUP FUNCTIONS

The philosophy of the DMUWG is that dredged material is a valuable resource - not a waste product. Further, dredged material can and should be used in an environmentally and economically acceptable manner that is beneficial to the people of the region. The DMUWG has attempted to identify all possible uses, determine the potential users, quantify the demand, and identify sites where the material can be placed so that it is accessible.

Table 1 identifies and assigns priority to the problems that were addressed by the DMUWG.

Table 1 - Problems addressed by the Dredged Material Uses Work Group

Problem	GREAT	Work group	Time frame	Priority	Rationale
1. Describe dredged material.	Yes	Yes	-	1	To determine how the material can be used, its physical and chemical properties must be identified and described.
2. Identify uses.	Yes	Yes	-	2	To determine and identify potential users, all possible uses must be known. For example, if the material is not suitable as a fine aggregate in concrete, concrete companies would not be potential users.
3. Identify potential users and areas of demand.	Yes	Yes	-	3	To determine how much material normally dredged could be used beneficially, it is necessary to identify all potential users and how much material each could use. It is also desirable to identify the areas of demand and the relation between the locations of demand and dredging.
4. Identify potential beneficial use disposal/stockpile sites.	Yes	Yes	-	3	To assure that dredged material is accessible to persons, firms, municipalities, and agencies wishing to use it, accessible stockpile areas must be identified. DMUWG will identify areas accessible to potential users. Areas within reach of present Corps dredging equipment will be given special attention for immediate use.
5. Determine economic impact on sand and gravel companies along river corridor of providing "free" material for potential users.	Yes	Yes	-	4	The economic impact on sand and gravel companies of providing sand to potential users could have serious repercussions. Ways to minimize these effects will be investigated.
6. Determine means of transporting material to areas of demand from stockpile/ disposal sites.	Yes	No	-	5	The Material and Equipment Needs Work Group will evaluate means of transporting material from stockpile area to areas of demand.

V. MATERIAL DESCRIPTION

The exact physical, chemical, and biological properties of dredged material must be known to determine its suitability for all potential beneficial uses. To accomplish this task, a ponar dredge was used to collect 104 bottom sediment samples from the main channel of the GREAT I study area during 1974. Serco Laboratories, Roseville, Minnesota, tested the samples to determine the physical properties (particle size) and chemical composition of the sediments. The results are shown in Attachment 1.

An additional nine samples were taken directly from existing dredged material disposal piles and analyzed for their physical properties. These samples were collected in conjunction with a study to determine the suitability of the material as a fine aggregate in concrete. The study was conducted by the University of Wisconsin - Platteville and is discussed in further detail in Chapter VII.

The St. Paul District, Corps of Engineers also analyzed the physical properties of sediments from the main channel, spoil piles, and major tributaries. The results of this study can be found in the 9-Foot Navigation Channel Final Environmental Impact Statement (U.S. Army Corps of Engineers, 1974). The results of this study compare closely to the findings of the work group's analysis.

Sieve analysis indicates the particle size and gradation (percent of sample falling into specific size categories) of a particular sediment sample. The particle size distribution is determined by separation with a series of standard screens; a hydrometer is used for very fine sediments. The screen sizes used in the sieve analysis for sand are numbers 4, 8, 16, 30, 50, and 100. These numbers indicate the number of holes per square inch. Particle size and gradation are essential considerations when determining the suitability of sandy sediments for potential uses.

On the basis of the sieve analysis data, all samples were assigned the appropriate Fineness Modulus (FM), an index used to measure the fine-fineness or coarseness of sand. The FM is computed by adding the cumulative percentages retained on the six standard size screens and dividing the sum by 100 (Meritt, 1968). Table 2 graphs the FM of each sample by river mile for the entire study area. The table also illustrates the effects on particle size of tributaries, locks and dams, and the natural sorting of sediments as they advance downstream.

Table 2 - Fineness Modulus (particle size) of sediment samples taken from the main channel of the Upper Mississippi River

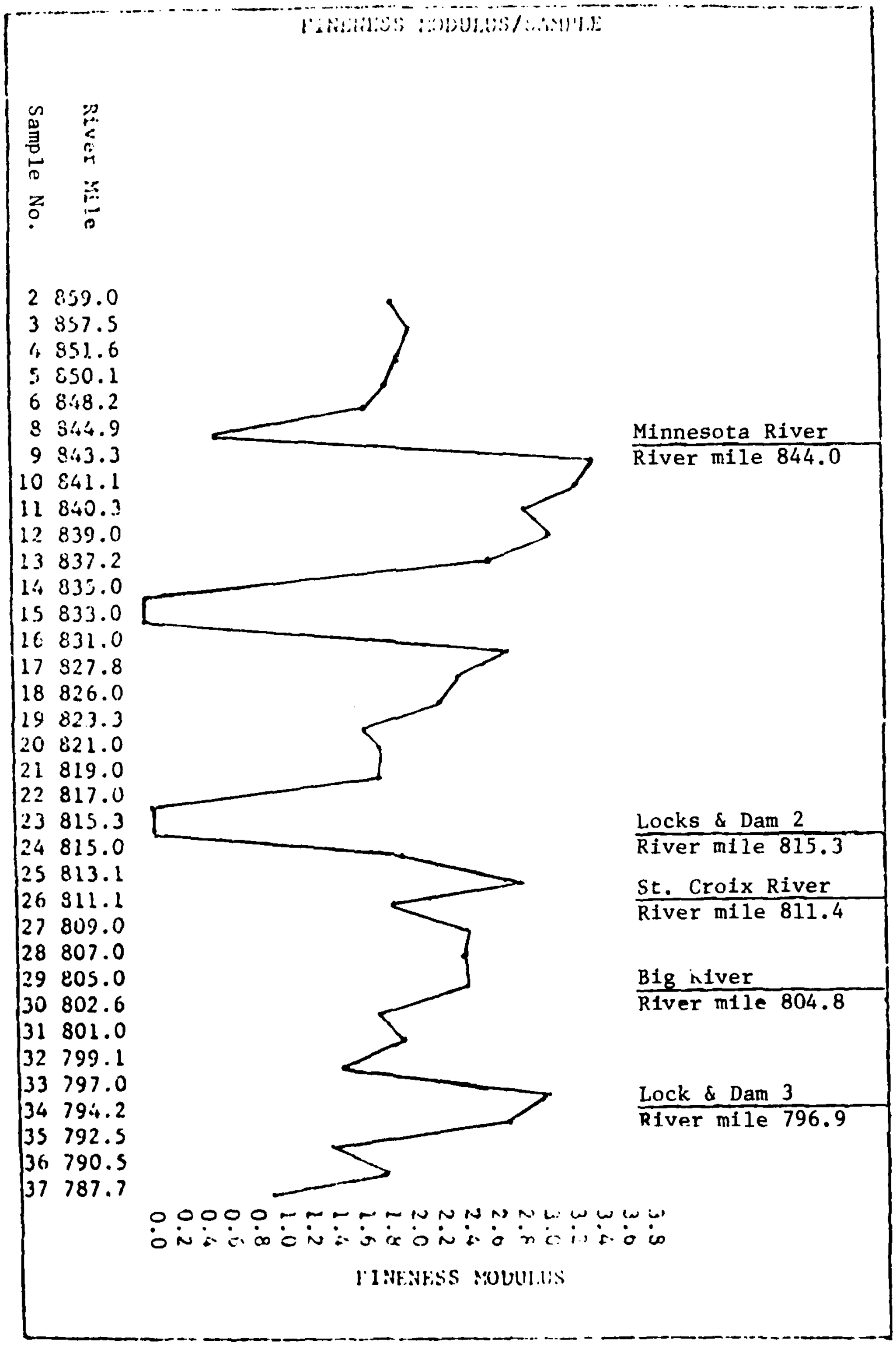


Table 2 - Fineness Modulus (particle size) of sediment samples taken from the main channel of the Upper Mississippi River (cont)

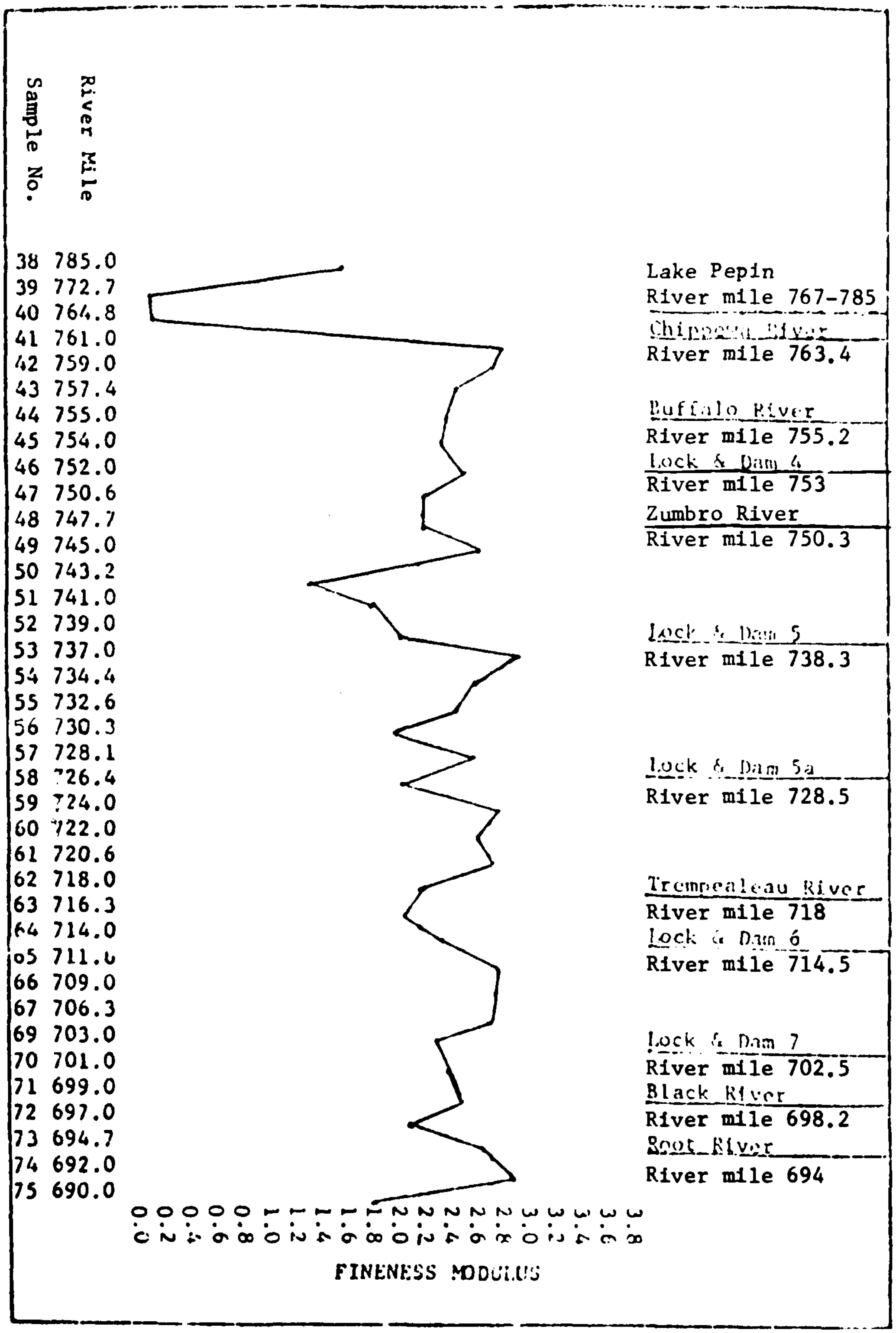
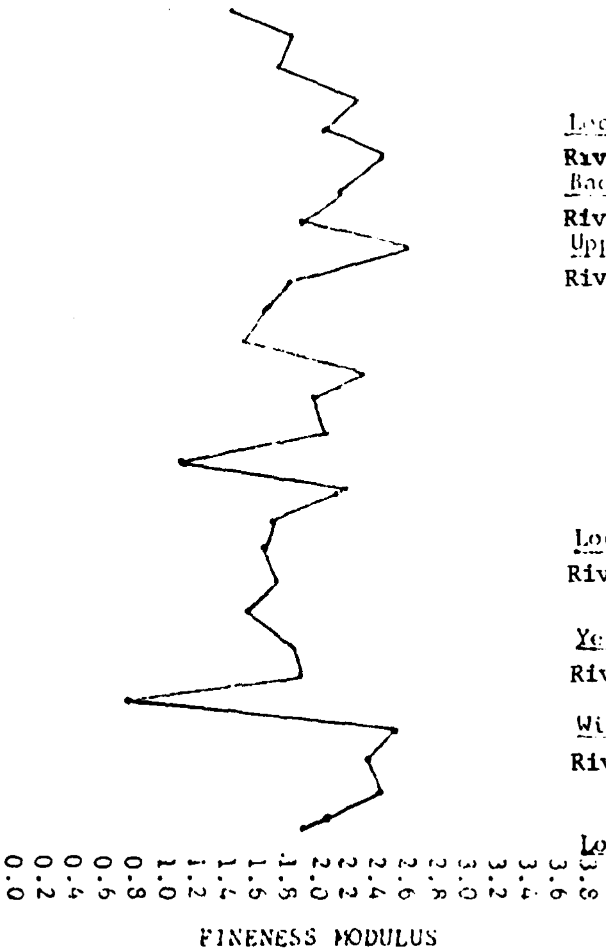


Table 2 - Fineness Modulus (particle size) of sediment samples taken from the main channel of the Upper Mississippi River (cont)

Sample No.	River Mile
76	688.0
77	686.0
78	684.0
79	682.0
80	680.0
81	678.0
82	676.0
83	674.0
84	671.4
85	669.3
86	667.4
87	664.4
88	662.6
89	660.5
90	658.6
91	656.0
92	654.0
93	651.0
94	648.1
95	646.2
96	643.2
98	637.0
99	633.0
100	632.2
101	631.0
102	627.6
103	624.0
104	621.0
105	618.5



Lock & Dam 8
River mile 679.3

Bad Axe River
River mile 675.1

Upper Iowa River
River mile 671.1

Lock & Dam 9
River mile 648

Yellow River
River mile 937.6

Wisconsin River
River mile 630.8

Lock & Dam 10
River mile 615.1

The FM ranged from 3.6 to 0.79 with fluctuations common along the entire study area. These fluctuations, except for those of Lake Pepin sediments, can be attributed to localized physical characteristics of the river channel such as wing dams, closing dams, running sloughs, adjacent backwaters, channel width, etc. The physical characteristics affect the velocity and degree of scouring in the channel which determine whether fine or coarse sediments are deposited at a given location. These physical characteristics are not static. As a result, the FM at a particular site can be expected to vary according to seasons and water levels.

Four samples in pool 2 and the two samples in Lake Pepin were fine enough to require testing by hydrometer. These six samples are not applicable to the FM index.

Those sediments sampled near the locks and dams have higher FM levels (coarser sediment) than the sediments farther upstream and downstream. This difference results from the bottom draw characteristics of tainter and roller gates which pass the flow underneath thus increasing current velocity along the bottom resulting in increased scouring.

The tributaries appear to have different effects on the FM. Lower FM values (finer sediments) immediately downstream of the mouth may indicate those tributaries are transporting finer sediments. The following tributaries exhibit this characteristic: St. Croix, Big, Buffalo, Trempealeau, Black, Bad Axe, Upper Iowa, and Wisconsin Rivers. The Minnesota, Chippewa, and Root Rivers appear to transport coarser sediment which causes a higher FM value. Lake Pepin, because of its ponding effect, resulted in an FM value of 0. Below Lake Pepin, the lower pools (8, 9, and 10) have average FM values lower than the average FM values for the upper pools (4, 5A, and 5).

FM does not give a definite indication of grading since an infinite number of gradings may give the same value for FM. Grading was determined for each sample because of its importance for determining the suitability of a sediment for potential uses. Table 3 indicates grading by giving the percent of each sample falling into the size categories of fine gravel, coarse sand, medium sand, fine sand, and silt. The grain sizes range from fine gravel (15.0 mm) to silt (smaller than 0.05 mm). However, neither extreme was common; 65 percent of the values listed in table 3 fell within the two columns titled medium and fine sand.

Table 3 - Grading (percent of sample falling into specific size categories) of sediment samples taken from the main channel of the Upper Mississippi River

		Grading (percent)					
	River	Gravel		Sand			
Sample	mile	Coarse	Fine	Coarse	Medium	Fine	Silt
2	859.0				57	43	
3	857.5		23	10	26	17	24
4	851.6			2	38	60	
5	850.1			1	34	65	
6	848.2			10	15	62	13
8	844.9		14	7	3	1	75
9	843.3			20	41	11	28
10	841.1		14	13	13	7	53
11	840.3		3	10	77	10	
12	839.0			30	50	11	9
13	837.2			5	79	16	
14	835.0						100
15	833.0						100
16	831.0			28	37	20	15
17	827.8			2	85	13	
18	826.0			3	77	18	2
19	823.3				7	93	
20	821.0			2	53	45	
21	819.0			2	50	47	1
22	817.0						100
23	815.3						100
24	815.0				50	50	
25	813.1		8	17	46	14	15
26	811.1			2	95	3	
27	809.0			1	87	12	
28	807.0			3	77	20	
29	805.0			5	70	25	
30	802.6			7	90	3	
31	801.0			3	52	45	
32	799.1				25	75	
33	797.0			15	74	8	3
34	794.2			2	90	8	
35	792.5				13	87	
36	790.5			3	37	60	
37	787.7			7	3	90	
38	785.0				25	75	
39	772.7						100
40	764.8						100
41	761.0		5	12	68	3	12
42	759.0			9	81	10	
43	757.4		2	8	65	23	2
44	755.0			3	57	40	
45	754.0			2	48	49	1
46	752.0			2	58	40	
47	750.6			2	60	35	3
48	747.7			3	60	37	
49	745.0		1	1	33	65	

Table 3 - Grading (percent of sample falling into specific size categories) of sediment samples taken from the main channel of the Upper Mississippi River (cont)

		Grading (percent)					
	River	Gravel		Sand			
Sample	mile	Coarse	Fine	Coarse	Medium	Fine	Silt
50	743.0				13	87	
51	741.0				30	70	
52	739.0		7	3	55	35	
53	737.0			16	73	9	2
54	734.4			6	75	15	4
55	732.6			7	58	35	
56	730.3			1	58	40	1
57	728.1		4	11	59	26	
58	726.4			2	58	40	
59	724.0		5	14	38	36	7
60	722.0			11	77	12	
61	720.6			12	80	8	
62	718.0			1	74	25	
63	716.3			1	62	37	
64	714.0			1	62	37	
65	711.6			7	85	6	2
66	709.0			8	80	12	
67	706.3			5	85	10	
69	703.0			1	77	22	
70	701.0			5	72	23	
71	699.0			1	89	10	
72	697.0			1	79	20	
73	694.7			1	89	10	
74	692.0		2	7	86	5	
75	690.0			1	44	55	
76	688.0			1	14	85	
77	686.0		3	7	32	53	5
78	684.0		3	2	53	42	
79	682.0			1	74	24	
80	680.0		3	2	48	47	
81	678.0			1	84	15	
82	676.0			1	82	17	
83	674.0			1	46	53	
84	671.4			7	75	18	
85	669.3			1	57	42	
86	667.4			1	38	61	
87	664.4			1	37	62	
88	662.6				72	28	
89	660.5				45	55	
90	658.6			1	69	30	
91	656.0			1	11	87	1
92	654.0		8	1	59	32	
93	651.0		3		25	72	

Table 3 - Grading (percent of sample falling into specific size categories) of sediment samples taken from the main channel of the Upper Mississippi River (cont)

Sample	River mile	Grading (percent)					
		Gravel		Sand			
		Coarse	Fine	Coarse	Medium	Fine	Silt
94	648.1		4		23	73	
95	646.2				37	63	
96	643.2				30	70	
98	637.0		5	6	24	65	
99	633.0			1	39	60	
100	632.2			1	1	89	9
101	631.0			22	37	41	
102	627.6			8	66	26	
103	624.0			5	88	7	
104	621.0			2	58	40	
105	618.5				35	65	

VI. MARKETING DREDGED MATERIAL

Several areas of concern were explored to obtain the answers to questions about the feasibility and practicality of marketing dredged material. The questions raised were:

1. Who would use the material and how great is the demand?

2. What impacts would be felt by private sand and gravel suppliers?

3. What legal restraints may be imposed?

Marketing Study

The DMJWG conducted a marketing study to determine, document, and quantify the demand for dredged material. The material use survey form on pages 18 and 19 was completed by interviewing State. city and county officials (primarily directors of public works); city engineers; and county and State highway engineers. The Marketing Study was conducted to quantify the demand for dredged material, identify potential uses, and document the current cost for sand. The information obtained was used by the work group to evaluate the alternative pool plans (Chapter IX).

The study concentrated on the counties, townships, and municipalities located within 10 miles of the river. Several communities indicated a demand for large amounts of fill to be used for proposed development projects. These projects are tentative but illustrate the demand for fill beyond 1985. Surveyed users and their demands are identified in attachment 5.

MATERIAL USE SURVEY

DATE: ____________________

NAME: ____________________

ADDRESS: ____________________

PHONE: ____________ CONTACT: ____________

1. Do you (buy, sell) sand? ____________
(Yes, no)

If "sell" - do you obtain material by dredging? ________

Use	Ave. Annual Vol. (period of record)
a. fill sand	________ cu. yds. (________)
b. de-icing sand	________ cu. yds. (________)
c. Concrete sand	________ cu. yds. (________)
d. asphalt sand	________ cu. yds. (________)
e. other	________ cu. yds. (________)

2. Current cost per cubic yard? ____________

3. De-icing sand -

a. Frequency of use (often, occasional, once, never)
____

b. Suitability (good, fair, poor) ____________

Why? ____________________

4. Estimated needs -

			Total Est. Vol.
Current	________	cubic yards/year	________
Current-1985	________	ccubic yards/year	________
1985-2000	________	cubic yards/year	________
2000-2025	________	cubic yards/year	________

5. Would you use dredged material if stockpiles were accessible? ________ Purpose: ____________
(Yes,No)
____

6. How far are you willing to travel to obtain it? ________

7. Do you know of lands or projects which could be utilized for dredge material disposal? ________________ (Yes, No)
(Site noted and mapped ______________ for office use only)
Date

8. Who do you buy your sand from? Name: ______________
Address: ______________
Phone: ______________

Year	Cubic Yards Used	Total Cost/Year	Cost/Cubic Yard
1950			
1955			
1960			
1961			
1962			
1963			
1964			
1965			
1966			
1967			
1968			
1967			
1968			
1969			
1970			
1971			
1972			
1973			
1974			
1975			
1976			
1977			

The particular users identified by the study are accurate. The projected demands should be considered approximate because many variables must be considered when quantifying needs for sand. The DMUWG was not in a position to evaluate the feasibility of the various projects. As a result, all projected demands were included in table 4.

Table 4 - Demand summary - summarizes the annual and permanent fill demands and expected dredging volumes over the 40-year time frame

	Quantity (cubic yards)				
	Annual demands		Permanent fill projects	Dredging volumes	
Pool	Historic	Projected (1986-2025)	demand (1986-2025)	Historic	Projected (1986-2025)
1, 2, Minnesota River	95,400	3,816,000		249,360	7,287,000
St. Croix	8,605	344,200		31,622	1,269,000
3	70,960	2,838,400		70,060	2,703,000
4 upper	13,600	544,000	600,000	55,300	1,935,000
4 lower	30,450	1,218,000	75,000	68,187	1,590,000
5	14,500	580,000	0	76,775	2,963,000
5A	14,620	584,800	0	62,850	2,735,000
6	45,500	1,820,000	2,000,000	28,737	1,185,000
7	2,794	111,760	0	55,027	2,184,000
8	58,175	2,327,000	550,000	91,010	3,647,000
9	80,730	3,229,200	650,000	62,705	2,288,000
10	15,980	639,200	1,325,000	40,752	1,386,000
Total	451,314	18,052,560	5,200,000	892,385	31,172,000

The demands for dredged sand are classified as:

1. Annual Demand: Demand which is continual and recurring such as for ice control.

2. Permanent Fill Projects: Demand for sand as fill for proposed development projects.

The above classifications were important in the evaluation of the pool plans, discussed in Chapter IX.

The demands for dredged material played an essential role in the development of the channel maintenance plan (Chapter IX). This plan involved the selection of future disposal sites that have sufficient capacity to accommodate the entire dredging volume for 40 years (1986-2025). The process of planning for 40 years of disposal necessitated the projection of dredging volumes and annual demand figures (permanent fill projects remain unchanged by the 40-year projection). Table 4 lists by pool the annual and projected annual demand for 40 years, demand for permanent fill projects, and historic and projected dredging volumes. The total demand identified for the 40-year time frame is 23.2 million cubic yards. The estimated dredging volume is 31.2 million cubic yards; therefore, there is no identified demand for 8.0 million cubic yards. However, as stated above, the Marketing Study focused on counties, townships, and municipalities. The demands of riparian landowners and private industry have not been fully documented nor reflected in table 4. Therefore, the DMUWG believes a significant demand remains to be identified. If all demands, known and unknown, were satisfied, it is probable that all dredged material may be used beneficially.

The Marketing Study identified the 1977 price paid for sand and the distances users were willing to travel to pick up dredged material (see table 5). Many users could obtain dredted material at a lower cost than they can purchase similar material from other sources. If dredged material were used, less sand would have to be mined and the lives of existing quarries would be extended. In some areas, the quarries are becoming exhausted. Prices of sand have increased drastically since 1977 so the costs presented in table 5 are considered low. The reasons for price increases include increased fuel costs to haul sand and sand shortages in some areas which greatly increases hauling distances. If dredged material is accessible and hauling distances are less than those from other sources, the material will be used.

Table 5 - Costs of sand and distances users will travel (1977)

Pool	Range of cost paid for sand (1977 cost per cubic yard)	Average cost of sand (1977 cost per cubic yard)	Distance user willing to travel to pick up material (miles)
1	$1.25 - $2.00	$1.70	6 - 20
2	0.55 - 3.25	2.14	4 - 30
3	0.55 - 3.25	2.14	4 - 30
4 - Upper	0.95 1.85	1.67	3 - 20
4 - Lower	0.50 - 1.75	0.86	3 - 20
5	0.50 - 1.25	0.75	2 - 20
5A	0.50 - 1.25	0.68	2 - 20
6	0.15 - 2.00	0.77	2 - 20
7	1.00 - 1.75	1.17	3 - 20
8	0.30 - 3.75	1.20	3 - 20
9	0.35 - 1.50	0.94	5 - 25
10	0.45 - 2.25	1.41	5 - 25
St. Croix	0.55 - 1.80	1.35	5 - 35

Sand and Gravel Companies

Because of the implications of possible adverse economic impacts on the private sector, members of the DMUWG are continuing their efforts to identify and quantify the demand for material and possible effects on sand and gravel suppliers. The findings will be published as an addendum to this report in 1980.

Legal Study

The DMUWG researched the legal implications involved if dredged material were provided by the Corps of Engineers free of charge to potential beneficial users along the river. A legel study (Wakeford and MacDonald, 1974) was completed by the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. The study implied

that it may be unlawful for the Corps to provide dredged sand to private enterprise free of charge, but that the material could be given to government agencies or nonprofit organizations. The study did not address the following questions:

1. Can the Federal Government (Corps of Engineers) be held liable if private sand and gravel suppliers suffer adverse effects resulting from the free disposition of dredged material?

2. Are there any known legal restraints against dredging sand in one State and depositing it in another State for the purpose of making it available for beneficial uses?

In an attempt to answer these questions, the DMUWG's of GREAT I and GREAT II jointly initiated a legal study. The study is documented in Attachment 2 (Stewart, 1978).

The answer to the first question is unclear (Stewart, 1978). No direct legislation or test cases have addressed the problem; however, it appears unlikely that the Corps would be liable if the material were sold by bid. Private producers could bid on the material and could possibly obtain it at a lower cost than mining or dredging the material themselves.

The answer to the second question is also unclear (Stewart, 1978). All three States charge the user a royalty for sand and gravel removed by private enterprise. If the Corps sold the material to a profit-making body within Wisconsin or Minnesota, the user may be required to pay a royalty. The reason for the charge is that the river bottom is the property of the State. Iowa does not charge the royalty when the material is removed by the Corps, regardless of the use to which the Corps puts it (Stewart, 1978).

No direct legislation or test cases have addressed this question. Wisconsin, Minnesota, and Iowa all waive royalties when materials are used by governmental bodies for public purposes. Consequently, it is unlikely that these States would charge a royalty if the material is transported to another State for public use. Minnesota requires the remover to maintain daily records of the quantity removed. This record-keeping requirement would not be waived when the material was removed for a public purpose (Stewart, 1978).

VII. POTENTIAL USES

The DMUWG has identified and researched many potential uses for dredged material. Fill and ice control appear to be the best and most feasible uses for large quantities of dredged material. Other uses investigated were glass, concrete, bituminous mix, and as a soil conditioner when mixed with additives. Masonry sand (mortar) and foundry sand were not investigated,because of the limited quantities used for these purposes. The GREAT II DMUWG is researching these and other beneficial uses of dredged material.

Fill

Dredged material from the main channel has proven to be well suited for fill and has been used exclusively in many fill projects. It is generally well suited for roadbed construction, backfill for building construction and sewer and water pipelines, and landfill. Sediments from some locations are too fine or contain levels of organic material or contaminants that will result in the dredged material being unsuitable for fill. Sediments unusable for fill occur at the head of Lake Pepin (where the lack of current velocity results in the deposition of very fine sediment, occasionally containing high levels of pollutants), in the Minnesota River, and in a portion of pool 2.

In 1975, a project at Buffalo City, Wisconsin, successfully demonstrated the suitability of dredged material for fill. About 14,000 cubic yards of dredged material was used to raise and widen County Trunk Highway 00. The highway also serves as a flood control structure. This project is discussed in greater detail later in Chapter VII. Another project that used dredged material was a public marina at Alma, Wisconsin.

A tremendous demand for dredged material for use as fill has been documented by the Marketing Study (table 4). The Wisconsin Department of Transportation (DOT) is committed to use dredged material for fill in the La Crosse Lang Drive project. The project, a road improvement, is scheduled to begin in fall 1979. The DOT has indicated it would use dredged material stockpiled at Isle La Plume (up to 300,000 cubic yards). GREAT has recommended to the Corps of Engineers that all the material dredged from pools 7 and 8 be barged to Isle La Plume to accommodate this demand. In addition, the DOT is planning reconstruction of State Highway 35 from Genoa, Wisconsin, to the Chippewa River. The project will require a total of 1,090,000 cubic yards of fill material between the years 1978-2000. The DOT could use dredged material if the following three conditions were met (Anderson, 1977):

1. "Generally all material is needed to widen highway fill slopes in wetland areas and floodplains. Nonapproval of such uses by other agencies nullifies the need for material."

2. "The material will be required as a lump sum (generally in blocks of 2-300,000 cubic yards at a time). Small quantities of dredged material will have to be stockpiled yearly for our use."

3. "Movement of material from stockpile is not economically feasible for over 1 mile distance. The assumptions are that stockpiles are located adjacent to highways. The quantity of dredged material (used) will decrease in direct proportion to the distance the stockpile is from State Highway #35, becoming 0 at 1 mile."

The chief limiting factor when determining whether it is more economical to use dredged material or quarry run sand is the distance the material must be transported. Hauling costs vary, but average about $0.30 per cubic yard per mile (1977 costs). Therefore to incorporate the use of large quantities of dredged sand, it must be stockpiled so access will be as close as possible to the demand.

Table 6 lists the potential users that have indicated they would use dredged material for fill if it were available.

Table 6 - Potential users of dredged material for fill

WISCONSIN

Dept. of Transportation
Pierce County Highway Dept.
Diamond Bluff Township
Village of Bay City
Village of Prescott
Isabelle Township
Village of Maiden Rock
Maiden Rock Township
Oak Grove Township
Buffalo County Highway Dept.
Alma Township
Alma Rod & Gun Club
Village of Alma
Belvidere Township
Village of Cochrane
Village of Buffalo City
Trempealeau County Highway Dept.
Trempealeau Township
Village of Trempealeau
La Crosse County
Onalaska Township
City of La Crosse
Campbell Township
Vernon County Highway Dept.
Bergen Township
Village of Stoddard
Village of De Soto
Crawford County Highway Dept.
Village of Ferryville
Village of Lynxville

MINNESOTA

Mendota Heights
Dakota County Highway Dept.
City of Cottage Grove
City of Hastings
Dept. of Transportation
City of Red Wing
City of Lake City
Wabasha Transfer
Winona County Highway Dept.
Mount Vernon Township
City of Winona
Winona Township
Dresbach Township
Hokah Township
La Crescent Township
Village of La Crescent

IOWA

Allamakee County Highway Dept.
Village of Lansing
Village of Marquette
Village of McGregor
Village of Guttenberg

Ice Control

Much of the material dredged from the main channel is well suited for use as ice control. Generally, the natural deposition and sorting of sediments results in uniform grain sizes. Uniform size is important to prevent plugging of the deicing truck spreaders.

The Marketing Study documented a substantial demand for dredged material for use as highway ice control. Table 7 lists the potential users that have indicated they would use dredged sand for ice control if it were available.

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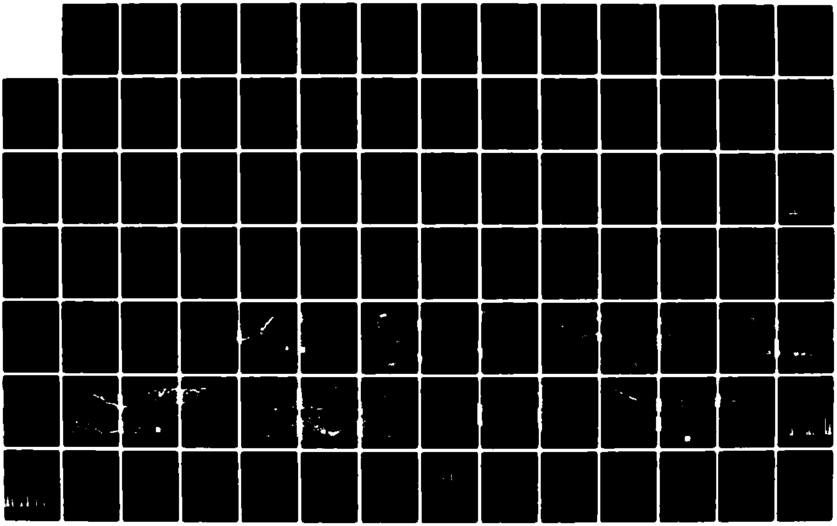


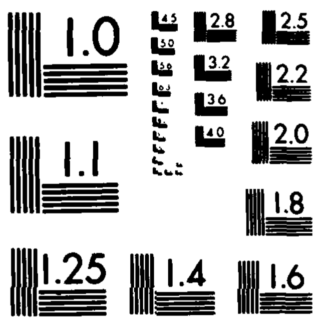


Table 7 - Potential users of dredged material for ice control

WISCONSIN

Dept. of Transportation
Pierce County Highway Dept.
Diamond Bluff Township
Village of Bay City
Village of Prescott
Isabelle Township
Village of Maiden Rock
Maiden Rock Township
Oak Grove Township
Buffalo County Highway Dept.
Alma Township
Alma Rod & Gun Club
Village of Alma
Belvidere Township
Village of Cochrane
Village of Buffalo City
Trempealeau County Highway Dept.
Trempealeau Township
Village of Trempealeau
La Crosse County
Onalaska Township
City of La Crosse
Campbell Township
Vernon County Highway Dept.
Bergen Township
Village of Stoddard
Village of De Soto
Crawford County Highway Dept.
Village of Ferryville
Village of Lynxville

MINNESOTA

Mendota Heights
Dakota County Highway Dept.
City of Cottage Grove
City of Hastings
Dept. of Transportation
City of Red Wing
City of Lake City
Wabasha Transfer
Winona County Highway Dept.
Mount Vernon Township
City of Winona
Winona Township
Dresbach Township
Hokah Township
La Crescent Township
Village of La Crescent

IOWA

Allamakee County Highway Dept.
Village of Lansing
Village of Marquette
Village of McGregor
Village of Guttenberg

Several counties in Minnesota have stated that the grains are too round, causing poor abrasiveness on ice and high skid characteristics. The roundness of the grains is the result of the effects of rolling along the river bottom. These counties have indicated a preference for quarry run sand. However, most quarry run sand being used for ice control along the river was deposited by water during some period of geologic history and, therefore, may exhibit characteristics similar to those of dredged sand.

The suitability of dredged sand for ice control has been well demonstrated by the Buffalo County Highway Department. The county has used dredged sand as a major source of material for ice control for the past 10 to 12 years, ever since dredged material was first disposed of in an accessible area. Mr. Bergie Ritscher, Buffalo County Highway Commissioner, has stated the dredged sand is very desirable because it is so clean and well sorted that screening is not necessary (Ritscher, 1978 personal communication).

Greater educational efforts and an honest trial period may result in increased use of dredged material for ice control.

Concrete

The Department of Civil Engineering, University of Wisconsin - Platteville, was contracted to research the feasibility of using dredged sand as a concrete aggregate. The results are found in Attachment 3 (Faherty, 1976).

Nine samples of dredged material were collected directly from existing disposal piles. The material was used as fine aggregate in concrete which was then tested for compressive strength and resistance to freeze-thaw cycles. The concrete was compared to samples made with Janesville Sand as the fine aggregate. The dredged material was not processed or conditioned (such as removing deleterious materials).

The concrete made with dredged material attained a somewhat lower ultimate strength. The strength ranged from 75 percent (pool 10) to 85 percent (pool 9) of that of the control. The concrete can be strengthened by increasing the cement content or pretreating the sand, but either would be costly (Faherty, 1976). However, dredged material could be used in the manufacture of concrete products where strength is not a limiting factor such as patio slabs, sidewalks, and outdoor decorations. Other possible uses for dredged sand may be for plaster and mortar where fineness is desirable to eliminate porosity.

The Fineness Modulus (FM) range of fine aggregate suitable for concrete is from 3.05 to 2.26 with a recommended FM of 2.68 (American Society for Testing Materials, 1950). Table 8 indicates the maximum, minimum, and recommended FM for determining the suitability of a sediment sample for concrete. Those samples falling within the acceptable FM range for concrete may not be suitable because of other undesirable characteristics such as the presence of deleterious materials or inorganic pollutants.

Table 8 - Fineness Modulus of sediment samples taken from the main channel of the Upper Mississippi River compared to Fineness Modulus range suitable for concrete

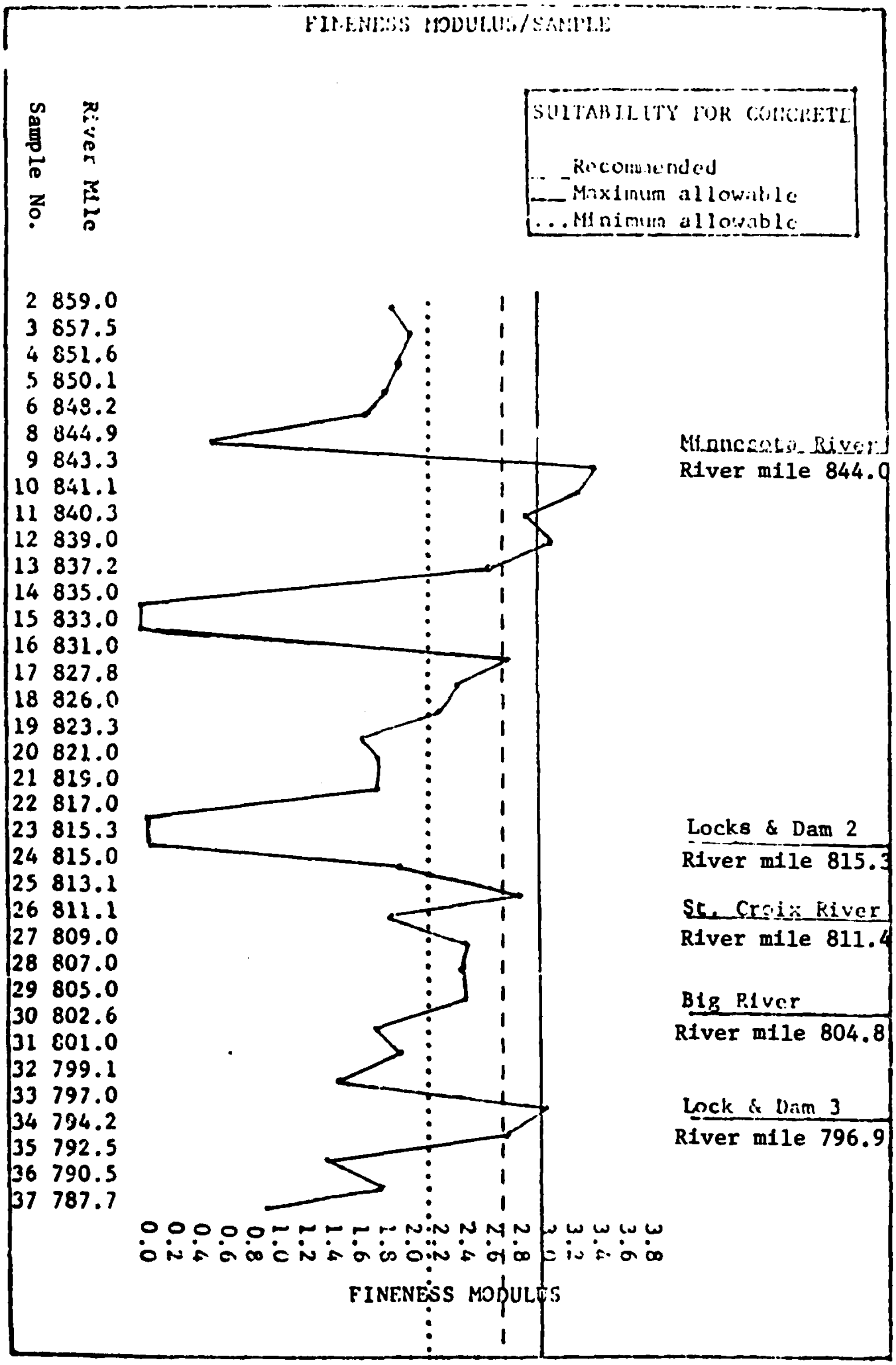


Table 8 - Fineness Modulus of sediment samples taken from the main channel of the Upper Mississippi River compared to Fineness Modulus range suitable for concrete (cont)

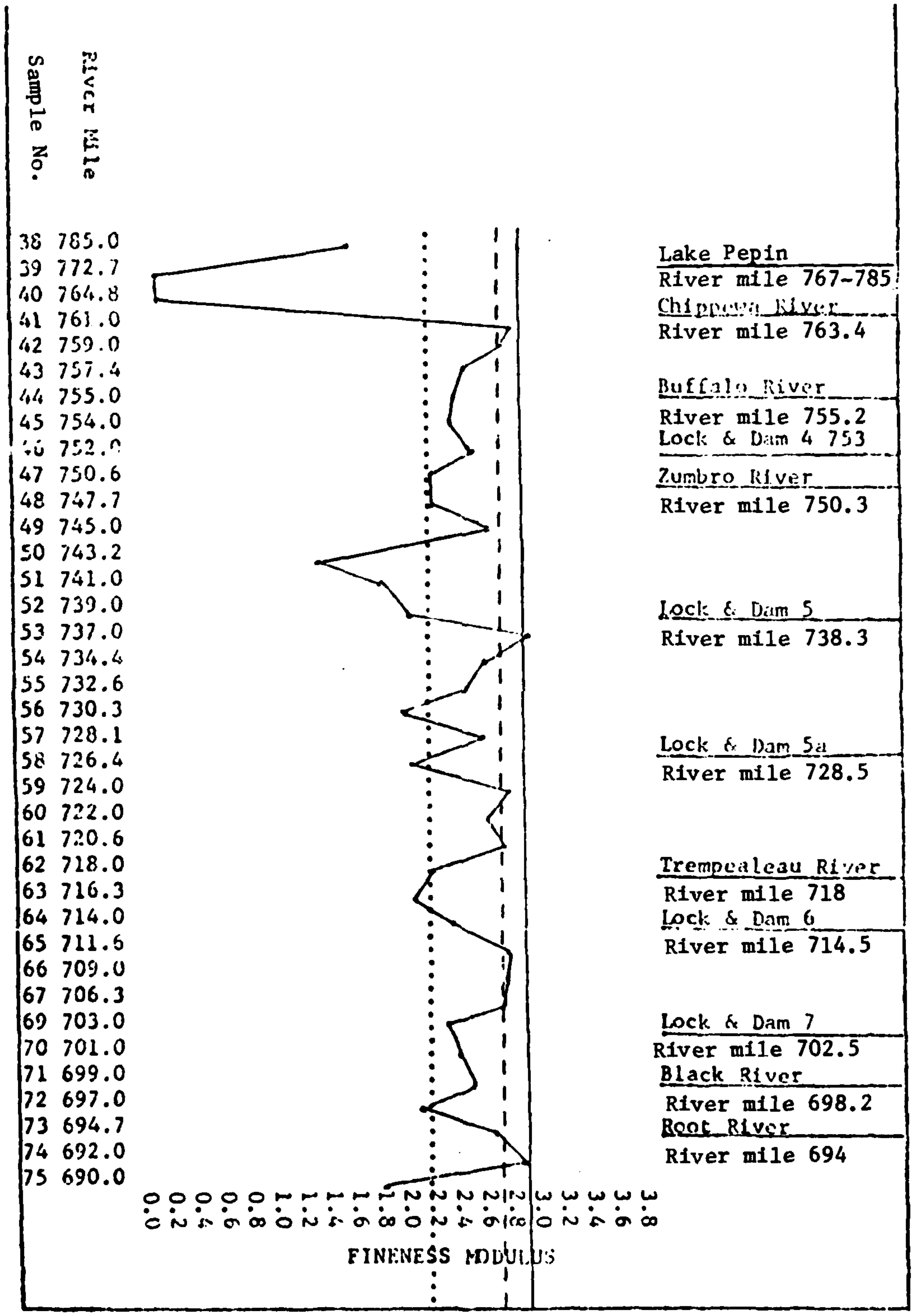
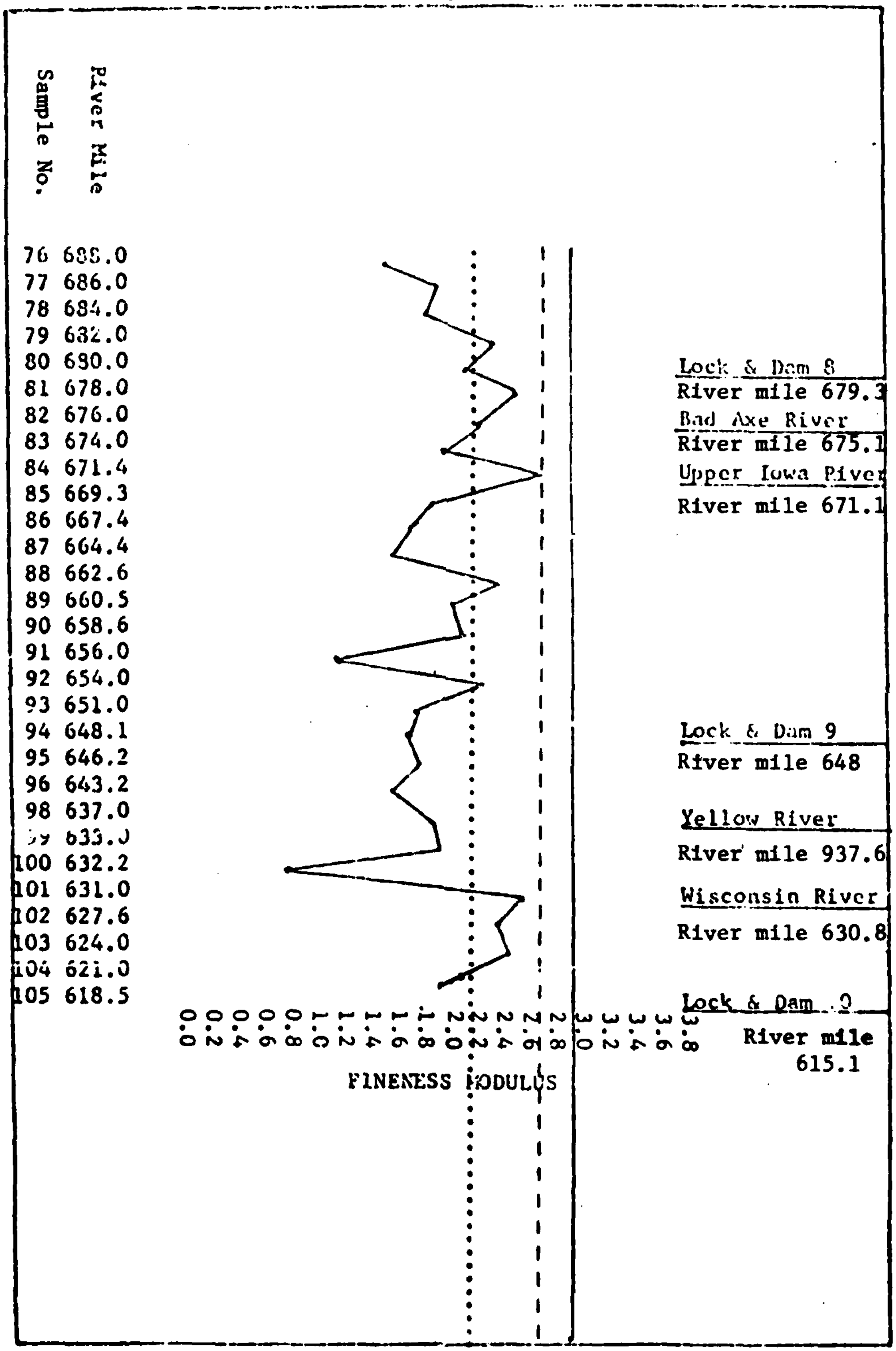


Table 8 - Fineness Modulus of sediment samples taken from the main channel of the Upper Mississippi River compared to Fineness Modulus range suitable for concrete (cont)



The recommended grading range of sand suitable for use as a fine aggregate in concrete is shown in table 9.

Table 9 - Recommended grading range for sand to be used as a fine aggregate in concrete

Grading	Composition (percent)			
	Fine gravel	Coarse sand	Medium sand	Fine sand
Maximum	5	14	56	25
Recommended		16	52	32
Minimum		8	47	45

Comparison of these figures to the actual sample gradings on table 3 indicates that the majority of the samples are more uniformly sorted and finer than is recommended for concrete.

Grading and FM are not the only characteristics to consider when determining if a sand is suitable for concrete. Other important factors are cleanliness, soundness, strength, and particle shape. Aggregates are considered clean if they are free from excess clay, silt, mica, organic matter, chemical salts, and coated grains. An aggregate is physically sound if it retains its dimensional stability under temperature or moisture change and resists weathering without decomposition.

For those samples that are close to, but do not quite meet, the specifications for concrete, several processes are available to improve their quality. For example, washing may be used to remove particle coatings or change gradation.

The sediments from the main channel have chemical compositions that are generally acceptable for concrete. Their levels of organic matter, sulfates, oxides, inorganic salts, and other chemicals are low enough to be acceptable. The inorganic compounds do not affect concrete to any great extent.

A more comprehensive study to determine the productive uses of dredged material is being conducted by the GREAT II DMUWG. Drs. Robert Lohnes and Dah-Yinn Lee of the Civil Engineering Department at Iowa State University will study the suitability of using dredged sand as the fine aggregate in mortar, concrete, and asphaltic concrete. Mortar strength will be determined for representative samples. Various concrete trial mixes will be tested using two coarse aggregates and three water-cement ratios for each sand sample. Various asphaltic concrete mixes will be tested using two coarse aggregates and fine asphalt binder content mixes for each sand sample. Standard concrete testing cylinders will be made from each of the mixes and tested for durability. Tests will include freeze-thaw, compressive strength, elastic modulus, indirect tensile strength, modulus of rupture, and the Marshall Method for asphaltic concrete. It is hoped new concrete mixes can be developed that will greatly add to the usefulness of the dredged sand. Redi-Mix dealers along the length of the river will be contacted to determine the possibilities of having them change their present mix to a new mixture using dredged sand.

Concrete companies are finding that in some areas sand is becoming increasingly difficult and expensive to obtain. This trend is a result of changing land values, continued development of rural lands, and increased pressure to resist "defacing" the land. As sand becomes more expensive, the economic feasibility of using dredged material will increase. In the future, it could be more economical to pretreat dredged sand and use it as a fine aggregate than to mine sand from quarries.

Bituminous Surface Mix

Asphalt concrete can be made using limestone rock or igneous gravel. Igneous gravel does not require the addition of sand in the bituminous mix because sand particles are already present among the aggregate.

When limestone rock is used in the surface layer, the Wisconsin DOT specifications require the addition of sand. The sand particles fill voids between the limestone rocks and improve the workability of the bituminous mix. The most desirable sand would be clean and coarse enough to allow only a small percentage passing the number 200 screen size. Almost all dredged sediments from the main channel could be used as blending sand in bituminous surfacing with limestone aggregate. Hydraulic dredging operations wash away the organic impurities and the particles finer than number 200 screen size. Wisconsin counties adjacent to the Mississippi River use the limestone aggregate and could use dredged material as a blending sand. Dredged material has been used as a blending sand in asphalt for some portions of State Highway 35.

The State DOT's of Wisconsin, Minnesota, and Iowa were asked if they would accept dredged sand in bituminous surfacing.

Wisconsin replied: "The materials could be used as a blending sand for aggregate for bituminous mixtures to correct gradations of the primary aggregate or to improve other properties of the mixture" (Zuehlke, 1976).

Minnesota replied: "The dredged sand samples proved too fine to meet our specifications requirements. The asphalt content requirement would be high and the skid resistance would probably be low" (Hinmelman, 1976).

Iowa replied: "Some of the dredged material at times would be suitable for use in asphaltic concrete" (De Young, 1977).

The differences between the States result from differences in specifications.

Glass

Dr. Britton of the Research and Production Department of the Corning Glass Works in Corning, New York, indicated that sand used for glass manufacture must be at least 98.5 percent pure silica (SiO_2) and have an iron content of a fraction of 1 percent. Dredged material from the Mississippi River varies in silica composition from 50 to 75 percent (U.S. Army Corps of Engineers, 1974). Therefore, dredged sand would not be suitable for glass manufacture. Dr. Britton indicated that Corning obtains its silica from pure quartzite deposits in Pennsylvania. He said that separation of the silica from the dredged sand is not practical or economically feasible.

Mr. Sheldon of the American Ceramic Society in Columbus, Ohio, confirmed Dr. Britton's statements and indicated that he knows of no use of sand in ceramic manufacture which has a silica content of less than 97 percent (Minnesota Department of Natural Resources, 1976).

Soil Conditioner

A $5,000 pilot study was undertaken in June 1976 to test the feasibility of mixing dredged sand with other locally abundant waste materials and using it as a soil substitute or soil additive. A copy of the final report is included as Attachment 4. The project was cost shared in cooperation with Dairyland Power Cooperative, the Mississippi River Regional Planning Commission, and GREAT. The city of La Crosse, Erickson Hardwoods, Inc., and La Crosse Lutheran Hospital also deserve recognition for their excellent cooperation in the project.

The purpose of the study was to evaluate the potential for creating topsoil or a soil conditioner to be used in conjunction with the reclamation of open-pit mines. On the basis of the study results, Commonwealth Associates in Jackson, Michigan, intended to initiate a follow-up study to determine the feasibility of transporting the "soil" to the coal mining areas of the western States on returning unit trains. However, the study was never initiated because the Electric Power Research Institute refused to provide funding.

The project involved the mixing of sawdust and sewage sludge and allowing the mixture to compost. Two sludge/sawdust compost piles were constructed on La Crosse Lutheran Hospital property, one on 17 June 1976 and the other on 7 August 1976. To insure adequate levels of oxygen during the critical first stages of composting, perforated plastic pipe was buried within the piles. Air was drawn into the piles and exhausted through small piles of sawdust by electric blowers operating on an automatic timer. Providing sufficient oxygen prevented the piles from composting anaerobically which would emit methane gas as a by-product and is usually associated with foul odors. No odor problems or complaints were associated with the piles.

Temperature and oxygen levels at various depths within the piles were monitored daily by personnel from each of the participating agencies. Temperature within the piles is one indication of composting progress. Sufficiently high or low temperatures can kill or inhibit growth of organisms.

By September 1976, both piles were completely composted and the material was transferred to the University of Wisconsin-Madison where it was mixed with sand and fly ash and put through greenhouse tests to determine its suitability as a soil additive. Corn germination tests resulted in 100-percent germination, but the plants showed nitrogen deficiencies. The addition of nitrogen resulted in further decomposition leading to an increase in the salt content of the piles. The addition of nitrogen followed by a sufficiently long curing time should increase the nitrogen content of the mixture.

The principal drawbacks to the sludge/sawdust compost were high salt and low nitrogen levels. Adding fly ash increases the salinity of the soil. However, adding sand improves the material's physical properties. The compost has good potential as a soil additive, but as a gross medium by itself it has problems that are not easily remedied.

The conclusion of the compost study is that the compost "would best be utilized as a soil amendment to improve the moisture and nutrient status of sandy soils . . ." (Schutte and Converse, 1976).

High (greater than 10 feet) sand islands are characteristic of dredge disposal areas on the Upper Mississippi River. These relatively sterile sand islands often do not naturally revegetate because moisture is not retained well, thus creating a moisture deficiency for plants. Concern has been expressed over secondary movement of dredged material, eroded from these islands by wind and water, into the backwater lakes, wetlands, and side channels (McMahon and Eckblad, 1975; U.S. Army Corps of Engineers, 1975; Stone, 1975). Secondary movement of dredged material may also increase channel maintenance dredging.

Placing compost on top of these islands and mixing it into the top 2 to 3 feet of sand will improve the moisture holding capability and nutrient content of the soil, thus increasing the revegetation potential.

Numerous other studies have been conducted to determine the value of various composts for revegetation of strip mines, taconite tailings, dredged material, etc. Larson (1974) tried to revegetate dredged material islands on the Mississippi River. This study demonstrated a need for a mulch or compost material and that artificial watering would help. McMahon and Eckblad (1975) used sewage sludge to try to revegetate Mississippi River dredged material islands. They had limited success the first year with most plants but noted that natural prairie grasses did well during the second and third years.

McMahon and Eckblad (1975) also tried whey and found it was conducive to seed germination and plant growth. They felt whey worked well because it formed a crust, increasing moisture holding ability of the sand while reducing wind erosion. Seedlings and rain were able to penetrate this crust, therefore enhancing its value. Because the

Upper Mississippi River is in the heart of America's dairy country and whey is often considered a waste product, whey would be readily available in any revegetation program.

The disposal of sewage sludge is a continuing and expensive problem for all communities. The placement of sludge, as a constituent of compost, on disposal islands could provide an acceptable, and perhaps economical, alternative for the disposal of sludge.

Possible legal restraints are associated with the placement of compost, whey, or sewage sludge in the floodplain of the Mississippi River. These materials may be considered a solid waste. The placement of solid waste is strictly limited to licensed landfill sites which are prohibited in floodplain areas. Implementation of this proposal may require specific legislation. A legal study should be conducted to determine the status of current laws, codes, and regulations. If necessary, legislative language allowing placement of soil conditioners should be developed.

Buffalo City Project

In October 1975, GREAT I sponsored and funded a pilot project that successfully demonstrated an ideal beneficial use for dredged material. The project involved dredging a backwater side channel leading into Belvidere Slough (river mile 745.8) and using the dredged material beneficially.

Since the 1965 flood, the backwaters around Buffalo City have had an increasing sedimentation problem. In recent years, the backwater areas became shallow enough to restrict recreational boat traffic from reaching the main channel of the Mississippi River. Buffalo City is a resort town and relies on its access to the river. Loss of access would cause economic hardship to the area by denying recreational boaters, hunters, and fishermen an avenue to the river.

The project accomplished four objectives:

1. Dredging increased the width and depth of the access channel from Buffalo City to Belvidere Slough and the Mississippi River.

2. Approximately 14,200 cubic yards of dredged material were pumped more than a mile and used in the construction of a flood control levee that protects Buffalo City. The dredged material was provided at no cost to the city or county. The levee was created by raising, widening, and improving a portion of County Trunk Highway 00 that was overtopped during the 1965 flood.

3. The project demonstrated one of the beneficial uses of dredged material. Also demonstrated were the benefits to be gained from using the most appropriate equipment to accomplish a specific job. The dredging was accomplished by a Mud Cat because it is a small, shallow-draft, hydraulic dredge capable of pumping long distances. The project was the first known attempt to dredge backwaters so far from the main channel.

4. The project helped determine if dredging backwater channels can be used as an effective tool to keep these areas open for the benefit of recreational boaters. The Side Channel Work Group monitored the depth in the dredge cut during the falls of 1976 and 1977. The dredge cut has not measurably filled in and is still very usable by recreational boaters.

The channel was dredged 6 feet deep and 30 feet wide. This modification resulted in the flow pattern being slightly altered. However, this change is considered desirable in maintaining the aquatic life in the area. Turbidity created by the dredging was minimal because the sand was relatively clean. A hood around the cutterhead also

helped reduce turbidity. To insure that the sediments were not polluted, samples were taken before dredging by the Corps of Engineers and tested for presence of heavy metals and chemical oxygen demand (COD). No standard testing procedure has been set up to determine if sediments are considered unsuitable for fill because of pollution.

The contract cost for the dredging operation totaled $30,419 ($2.14 per cubic yard). A complete breakdown of operational costs is included in the Material and Equipment Needs Work Group Appendix. This pilot project was accomplished by persons unfamiliar with both the equipment and methods of handling the slurry. With additional experience, a considerable reduction in total cost would be anticipated.

Grey Cloud Island Vegetation Study

In April 1976, GREAT conducted a demonstration project on Grey Cloud Island to determine the potential for plant growth in dredged material rich in organics. Generally, the dredged material from the Mississippi River is too sterile to readily promote growth of vegetation. However, sediment samples taken from pool 2 (approximate river mile 823.5) indicated high nutritive qualities suggesting potential value as a soil conditioner. The project was a coordinated effort between GREAT, the Corps of Engineers, the J. F. Shiely Company, and the citizens of Grey Cloud Island.

The J. F. Shiely Company offered a plot of land at its Nelson Plant site on Lower Grey Cloud Island for the study. Approximately 6,000 to 10,000 cubic yards of dredged material were delivered to the Nelson plant dock and loaded directly into dump trucks by the Corps of Engineers and hauled to the test site. The test site was 200 feet long and 100 feet wide. The site was prepared using different combinations of existing topsoil and dredged material. The material was seeded and maintained by the J. F. Shiely Company.

The study was considered a test of the beneficial use of polluted dredged material. The Water Quality Work Group supervised the study, monitored the effects on subsurface water quality, and prepared a report on the study.

The 1976 growing season was very poor as a result of a drought. Little germination or growth occurred. No results were recorded. In September, a single crop (winter rye) planting scheme was initiated with provisions for watering the test site. Observations on 3 October reported a thick crop about 4 inches in height. Observations in April and May 1977 revealed a healthy crop with even growth over all areas of the plot and little weed growth. The crop was turned over in early May to ready the plots for summer planting.

A single crop planting scheme was used for the 1977 growing season. The study area was planted 26 May with smooth brome grass. Fertilizer was applied on 4 June 1977 at 50 pounds per acre. Germination was good. Employees of the J. F. Shiely Co. reported a uniformly health crop throughout the growing season. No water was needed for the growing season. Weeds were more numerous in the brone than in the winter rye. Alfalfa from the surrounding area was invading the study area indicating the suitability of dredged material as a growing medium.

The results of the pilot study show that dredged material can be used as a soil conditioner and a growing medium for plants. It should be noted that the pilot study was agriculturally oriented; potential for permanent vegetation cover can only be inferred. The key to successful vegetation growth on dredged material is early attention to watering and fertilization. The fall planting of a winter annual is a useful method of preparing the soil in later summer and fall (Dralle, 1977).

VIII. SITE IDENTIFICATION STUDY

The DMUWG investigated the study area to identify and document all potential dredged material placement sites. The criteria used for identification were:

1. The site was used previously by the Corps of Engineers for dredged material disposal.

2. The site is accessible by road to facilitate use of the material.

3. The site was identified as a potential permanent fill project location in the marketing study.

No attempt was made to evaluate the economic or environmental impacts associated with a potential site; this task belonged to other GREAT work groups.

Each site was assigned a two-part number: the first part is the pool number and the latter is the site number (example 9.27 is pool 9, site 27). The site number, landowner, and other information were recorded on the material placement evaluation forms (see sample on pages 45-49). Each work group had a section to complete indicating its evaluation and recommendation for the particular site. The sites were photographed and plotted on maps. All information was tabulated by pool.

When the fieldwork was completed, the sites were plotted on large-scale (1 inch = 800 feet) reproducible maps. The Plan Formulation Work Group used the sites to develop the alternative dredging plans. The sites selected by the alternative dredging plans were evaluated by each work group and submitted to the Plan Formulation Work Group. All work group evaluations were incorporated into the development of the final plans for placement of dredged material.

MATERIAL PLACEMENT EVALUATION FORM

Site No. ____________________ River Mile ____________________

Location ____

I. Land Owner

____

Name Address Phone

Contacted ____________________
Date

Permission to Use _____ Yes _____ No

Follow-Up Contact Req'd _____ Yes _____ No

Purpose:

II. Description of Area (wetland, upland, wooded, farmland, etc.)

III. Comments

A. Dredged Material Use Work Group Date ________________

- Road Access _____ Yes _____ No _____ Possible w/development

- RR Crossing Existing ____ Yes _____ No ____ Not Req'd

Location ____ Dist. _____ Direction

Type ____ Public

____ Private

If Private:

Name and Address of Owner ____

Permission to Use _____ Yes _____ No

- Type of Site

1) Temporary Stockpile Site _____ Yes _____ No

Owner will allow material to be hauled away for beneficial use _____ Yes _____ No

2) Permanent Use Site _____ Yes _____ No

Purpose for filling ______________________________

- Potential Material Users

1) Name ______________________________

Address ______________________________

Intended Use(s) ______________________________

Quantity Needed ______________________________

Distance to "Use" Area ______________________________

Comments:

(Use backside for additional users)

- Recommended for Use by Dredged Material Uses Work Group

_____ Yes _____ No

B. Floodplain Management Work Group (Date ______________)

Floodplain _____ Yes _____ No

Floodway _____ Yes _____ No

- Effective Flow Area _____ Yes _____ No

Comments:

Recommended for Use by Floodplain Management Work Group

_____ Yes _____ No

C. Material and Equipment Needs Work Group (Date __________)

Dist. from Historic Dredging Sites __________ Miles

Can be reached with - Wm. A. Thompson _____ Yes _____ No

Is Mullen req'd _____ Yes _____ No

- Derrickbarge Hauser _____ Yes _____ No

Water Depth adjacent to area

- Other equipment req'd

Type ______________________

Equip. Needed to transport material to area of demand ________

____

Comments:

Recommended for Use by Material and Equipment Needs Work Group

_____ Yes _____ No

D. Dredging Requirements Work Group (Date ______________)

Vol. dredged from nearest historic dredging site

	13 feet	12 feet	11 feet
Average Annual	_____ CY	_____ CY	_____ CY
Most	_____ CY	_____ CY	_____ CY
Least	_____ CY	_____ CY	_____ CY
Frequency	_____ CY	_____ CY	_____ CY

Probability of reducing dredging quantities by wing dam modification, etc. ______________ percent

Method ______________________________

Est. reduction ______________________________

Comments:

Recommended for Use by Dredging Requirements Work Group

_____ Yes _____ No

E. Fish and Wildlife Work Group (Date ______________)

Existing Habitat (in percent of Area)

Wildlife - Predominant Species ______________________

Nesting ______%, Feeding ______%, Other______%

Fish - Predominant Species ______________________

Spawning ______%, Feeding ______%, Other______%

Riprap present ___________ Yes ___________ No

Wing dam (closing dam) _______ Yes _______ No

Habitat Evaluation Attached ___________ Yes ___________ No

Comments: (Include other species, general value, class of wetlands, etc.)

Recommended for Use by Fish and Wildlife Management Work Group

___________ Yes ___________ No

F. Recreation Work Group (Date ______________________________)

Site is presently used for:

Boating and/or Swimming ___________ Yes ___________ No

Hunting ___________ Yes ___________ No

Fishing ___________ Yes ___________ No

General recreational pressure in vicinity:

_________ Heavy, ____________ Moderate, ________ Low

Site is being considered for future development

___________ Yes ___________ No

Purpose of development ____

The site has been surveyed for historical or archeological significance

____________ Yes ________ No ________ Not Req'd

Comments:

Recommended for Use by Recreation Work Group ______ Yes ______ No

G. Commercial Transportation Work Group ___________ Yes _________ No

Proximity of area to planned waterfront development

- Distance ____

- Type of development ____

Comments:

Recommended for Use by Commercial Transportation Work Group

_____________ Yes ________ No

H. Plan Formulation Work Group (Date ____________________)

Recommended for Use __________ Yes ____________ No

Permits Req'd

- Landowner (Private) ______ Obtained __________ Req'd
- State ______ Obtained __________ Req'd

  State __________ Permit ____________
- Federal ______ Obtained __________ Req'd

  Agency __________ Permit ____________

Transmitted to GREAT I for Action ____________________

Date

IX. EVALUATIONS OF ALTERNATIVE DREDGING PLANS

The alternative channel maintenance dredging plans developed for each pool are:

1. Most probable future without GREAT.

2. Selective placement.

3. Beneficial use.

4. Centralized placement.

5. Habitat enhancement.

6. Removal from floodplain.

7. Interim.

The eventual product of these alternative plans will be the GREAT I channel maintenance plan (Plan Formulation Work Group, 1979).

Each plan has a specific set of criteria associated with it. Disposal sites that met the criteria and were of sufficient capacity to accommodate the expected volumes were selected for the disposal of dredged material for each plan.

Each work group was given the responsibility to evaluate the plans from the standpoint of its interest. The evaluation conducted by the DMUWG was based on information obtained through the Marketing Study.

The evaluation included identifying the most likely users for each accessible disposal site and the quantity of dredged material demanded by the user. The amount of expected removal based on the annual demand at a particular site was calculated to determine the longevity of a site. Sites identified as permanent fill projects assumed no removal.

The evaluation determined the comparative dollar value of each plan by multiplying a particular user's current cost per cubic yard by his demand. Inflation was not considered; therefore, all dollar values represent 1978 costs. The sites recommended for use by the DMUWG are those that could supply the greatest number of users with sand.

Time, manpower, and budget limitations did not allow the Marketing Study to thoroughly address all the private sector needs. Therefore, the demand estimates can be considered low.

The DMUWG submitted its evaluations to the Plan Formulation Work Group. When all work group evaluations were received, the Plan Formulation Work Group developed the national economic development (NED) and the environmental quality (EQ) plans as required by the Water Resources Council's Principles and Standards. The NED plan involves a selection of sites that maximize national economic development. The EQ plan involves the selection of sites that maximize environmental concerns. Each work group's evaluation and appendix report included a selection of sites that best fit either the NED or EQ plan.

On the basis of the Plan Formulation Work Group evaluation of the NED and EQ sites, a selected plan was developed. A more complete explanation of the process and the result is contained in the GREAT I final report.

X. CONCLUSIONS

1. Dredged material is a valuable resource.

RATIONALE: The availability of sand in some reaches of the river is very limited. Obtaining sand in these reaches requires long distance hauling which increases costs. As inflation continues and land becomes more valuable, the costs of using quarry-run sand will continue to increase.

2. There is a large demand for dredged material.

RATIONALE: The marketing study surveyed many potential users of dredged material throughout the study area. The findings indicated the total demand for dredged material is nearly 70 percent of the projected dredging volume. This estimate can be considered low because all potential users were not contacted.

3. Dredged material can be made available in most reaches of the GREAT I study area.

RATIONALE: Dredged material has been provided to several communities along the river (La Crosse, Alma, and Fountain City, Wisconsin, and Winona and St. Paul, Minnesota) for beneficial uses. Dredged material could be provided to many more areas if different dredging equipment and/or additional accessible disposal sites were available.

4. Beneficial use of dredged material serves the environmental and economic interests of the area.

RATIONALE: Beneficial use of dredged material improves the environment of the river because the sand is removed from the system. The sand will not reenter the river and require redredging at a later date downstream. Economic interests are served because the dredged sand can often be used at a cheaper cost than purchasing quarry-run sand.

5. Dredged material cannot, at this time, be used economically as a fine aggregate in concrete.

RATIONALE: The majority of dredged sand is too fine and too well sorted for use in concrete. Tests have shown that concrete made with dredged sand has lower ultimate strength. It is possible to upgrade the sand, but the cost is presently prohibitive.

6. Dredged material can be used economically as a blending sand in asphalt.

RATIONALE: Dredged sand can be, and has been, used economically as a blending sand in asphalt concrete.

7. Dredged material can be economically used for landfill.

RATIONALE: Sand dredged from most of the main channel is free of contaminants and well suited for fill. Several projects that used large amounts of dredged material for fill have demonstrated its suitability.

8. Dredged material can be economically used for highway ice control.

RATIONALE: Dredged sand from the main channel is uniformly sorted and well suited for ice control. The suitability for ice control has been demonstrated by the Buffalo County, Wisconsin, Highway Department which has used dredged sand for many years.

9. The legal implications of providing dredged material free of charge to private enterprise are not known at this time.

RATIONALE: The legal study (Stewart, 1978) found that no direct legislation or test cases have addressed this problem. Therefore, test cases will have to be tried before these questions can be answered.

10. Dredged material can be used for the construction of flood control levees.

RATIONALE: The Buffalo City project and numerous instances in the Rock Island District (Corps of Engineers) demonstrate the suitability of constructing levees using dredged material from the main channel of the Mississippi River.

XI. RECOMMENDATIONS

The economic feasibility and costs of implementing the following recommendations were not determined by the DMUWG. The GREAT I and II Material and Equipment Needs Work Groups have the major responsibility for this determination. The economic feasibility of each recommendation should be determined before implementation.

1. Material dredged during normal channel maintenance should be placed so that it can be put to beneficial use.

   RATIONALE: Many users could purchase dredged material at a lower cost than they can purchase similar material from other sources. The use of dredged material would result in less mining of sand, thus extending the life of existing quarries. Removal would result in less sand in the river system which would benefit fish and wildlife habitat and might reduce future dredging.

   IMPLEMENTATION: Corps of Engineers.

2. Permanent dredged material stockpile sites should be established near population centers.

   RATIONALE: The Marketing Study has shown the greatest demands for dredged material are from populated areas. The continual removal of material would extend the life expectancy of a permanent stockpile site.

   The primary costs of dredged material are for transportation. Truck hauling costs are approximately $0.30 per cubic yard per mile. The Corps should make every possible effort to place the material close to areas of known demand. The placement of the dredged material in these areas will result in the material having more value to the users. This will help assure removal from the stockpile site and extend the site's life.

   IMPLEMENTATION: Corps of Engineers, Fish and Wildlife Service, States, local government.

3. The Corps of Engineers should request the necessary appropriations to purchase effective and efficient dredging equipment or contract with private firms. All State and Federal agencies should seek congressional support for this request.

RATIONALE: The Corps dredging equipment is not capable of transporting dredged material long distances. An exception is the Derrickbarge Hauser (a clamshell dredge), but it cannot remove large volumes of material within scheduled time constraints. Thus, equipment that would minimize environmental damage while transporting materials long distances to areas of known demand is needed. Effective new equipment could transport material across backwater areas, up inclines, and across land without major disturbance to reach stockpiles. A booster pump mounted on a truck or rail car could be used.

IMPLEMENTATION: Corps of Engineers.

4. A procedure to easily and quickly incorporate new sites for material placement as new demands appear should be established.

RATIONALE: New demand areas are continuously arising. Because existing procedures require obtaining permits that frequently take considerable time, a simplified procedure would reduce time delays and undoubtedly open up new beneficial sites. The new procedure should be adopted for use now as well as after GREAT is dissolved.

IMPLEMENTATION: Corps of Engineers, States, local governments.

5. The Corps of Engineers should provide dredged material to users free of charge. When legal restraints prevent this, the material should be sold at its "fair market value" as determined through bidding.

RATIONALE: Providing dredged material free of charge will increase the removal for beneficial use and result in greater life expectancy of the disposal site. Selling dredged material through competitive bidding would eliminate unfair competition with private sand and gravel suppliers.

IMPLEMENTATION: Corps of Engineers.

6. The Corps should determine if structures could be installed along the sides of the channel to cause sand to deposit at areas of continual high demand, such as population centers.

RATIONALE: Such a method may decrease the amount of maintenance for the 9-foot channel. The naturally deposited sand could be dredged and applied to nearby beneficial sites. The deposits may also provide beach areas for nearby population centers. The structures must be situated so navigation will not be impeded by the sand. The benefits of this recommendation should be weighed against environmental effects before construction.

IMPLEMENTATION: Corps of Engineers.

7. Private enterprise should explore the economic feasibility of transporting sand from dredged material islands to areas of demand.

RATIONALE: Portions of the river have large sand islands that are regularly used as disposal sites. La Crosse and Brownsville, Reads Landing, and Red Wing, Minnesota, are examples of such areas where the dredged material would be put to beneficial use if it were made accessible.

IMPLEMENTATION: Potential users.

8. Examine the economic feasibility of constructing railroad sidetracks adjacent to chronic dredging areas so dredged material can be transported to areas of high demand.

RATIONALE: Several chronic dredging areas do not have nearby approved disposal sites; finding sites in these areas will continually be a problem. Permanent railroad sidetracks adjacent to the dredge cut would allow hopper cars to remove the sand for beneficial use without blocking the tracks. The railroad could serve areas of high demand not normally reached by conventional dredging equipment.

IMPLEMENTATION: Corps of Engineers, States, railroad industry.

9. An economic feasibility study should be made of constructing a permanent pipeline with booster pumps adjacent to chronic dredging areas to transport dredged material to areas of high demand.

RATIONALE: Several chronic dredging areas do not have nearby approved disposal sites; finding sites in these areas will continually be a problem. Permanent pipeline with booster pumps adjacent to the dredge cut would allow removal for beneficial use.

IMPLEMENTATION: Corps of Engineers.

10. The potential beneficial uses of fine organic sediments should be studied. The studies should address the problems of contaminants and dewatering, often associated with fine organic material.

RATIONALE: The Fish and Wildlife Work Group recommended dredging in certain backwaters containing fine organic sediments. The potential uses of organic sediments may include fertilizers, black dirt fill, or soil additives. If the organic sediments

are unsuitable in dredged form, the study should determine if upgrading is economically feasible. Upgrading may include the addition of lime to raise a low pH or the addition of nitrogen, phosphorous, potassium, etc., to supplement nutrient deficiencies.

IMPLEMENTATION: Corps of Engineers, Fish and Wildlife Service, States.

11. The potential for making riprap using dredged material and cement should be studied.

RATIONALE: Making riprap from dredged material and cement (Simons and Chen, 1978) would provide an additional beneficial use and may result in large amounts of riprap becoming available at a cheaper cost. The riprap would be applied to protect unstable banks or disposal areas. Riprap provides a very desirable habitat for many species of fish, wildlife, and benthic organisms when used in the proper locations.

IMPLEMENTATION: Corps of Engineers.

12. An interagency organization, patterned after GREAT, should be established and given the authority to manage the Upper Mississippi River. The interagency organization should be made up of representatives from the agencies active in the GREAT study.

RATIONALE: The likelihood of implementing many of the DMUWG recommendations will be greater if management of the river is shared by many interests.

IMPLEMENTATION: Corps of Engineers, Fish and Wildlife Service, States, U.S. Geological Survey, U.S. Environmental Protection Agency, U.S. Department of Transportation, U.S. Department of Agriculture (Soil Conservative Service).

13. The Corps of Engineers should change its policies to allow acquisition of private lands for stockpiling of dredged material for beneficial use.

RATIONALE: Present Corps of Engineers policy prohibits acquisition of private land for disposal of dredged material whenever Federal land is available. This policy has prevented the stockpiling of dredged sand for beneficial use in various stretches of the river because federally owned islands were available. Disposal on islands results in the dredged material being unavailable to the users while violating floodplain standards, being subject to erosion, and causing adverse environmental impacts. An example of an area where acquisition of private land is recommended is Dresbach, Minnesota.

IMPLEMENTATION: Corps of Engineers.

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XIII. ATTACHMENTS

The attachments (except for attachment 5) are not bound with this report because of their length. Copies are available from:

Wisconsin Department of Natural Resources
State Office Building - Room 108
3550 Mormon Coulee Road
La Crosse, Wisconsin 54601

U.S. Army Corps of Engineers
St. Paul District
1135 U.S. Post Office & Custom House
St. Paul, Minnesota 55101

ATTACHMENT 5

LIST OF SURVEYED POTENTIAL USERS OF DREDGED MATERIALS AND THEIR DEMAND*

Prepared by Terry W. Marx and David M. Kennedy, 1980, Wisconsin Department of Natural Resources, La Crosse, Wisconsin

NOTE: Demand by some users is apportioned between more than one pool, and these names appear more than once. Also, because different departments in a governmental body have separate demands, some bodies are listed twice.

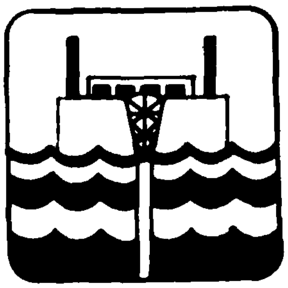
Pool	User	1981-1985 Short-term demand (cubic yards) for dredged material (all uses)	1986-2025 Long-term demand (cubic yards) for dredged material (all uses)
St. Croix	* Pierce County	10,000	40,000
	Clifton Township	2,000	16,000
	St. Croix County	21,000	168,000
	Washington County	15,000	120,000
Pools 1 - 2 Minnesota River	St. Paul	200,000	1,600,000
	Mendota Heights	2,000	16,000
	Minneapolis	200,000	1,600,000
	Hennepin County	75,000	600,000
Pool 3	* Pierce County	20,000	80,000
	Oak Grove Township	1,750	14,000
	Prescott Village	1,750	14,000
	Diamond Bluff Twnshp.	2,300	18,000
	Dakota County	212,500	1,700,000
	Hastings Village	90,000	720,000
	*Goodhue County	11,500	90,000
	*Washington County	15,000	120,000
Pool 4 - Upper	* Pierce County	30,000	120,000
	Isabelle Township	1,000	10,000
	Bay City Village	500	4,000
	Trenton Township	1,500	12,000
	*Goodhue County	11,500	90,000
	Red Wing City	23,500	180,000
Pool 4 - Lower	* Wabasha County	4,250	35,000
	Wabasha City	12,500	50,000
	Buffalo County	62,500	500,000
	Alma Township	2,500	20,000
	Alma Village	50,000	400,000
	Pepin County	18,000	146,000
	Pepin Township	2,500	20,000
Pool 5	* Wabasha County	4,250	35,000
	Kellogg Village	750	6,000
	Buffalo County	62,500	500,000
	Belvidere Township	2,500	20,000
	Cochrane Village	1,250	10,000
	Buffalo City	1,500	12,000

List of surveyed potential users of dredged materials and their demand (cont)

Pool	User	1981-1985 Short-term demand (cubic yards) for dredged material (all uses)	1986-2025 Long-term demand (cubic yards) for dredged material (all uses)
Pool 5A	*Buffalo County	62,500	500,000
	Milton Township	1,000	8,000
	Buffalo Town	1,500	12,000
	Fountain City	2,500	20,000
	*Winona County	5,000	20,000
	Minnesota City	600	4,800
Pool 6	Trempealeau County	33,000	42,000
	Trempealeau Twnshp.	10,000	80,000
	Trempealeau Village	500	4,000
	Buffalo County	62,500	500,000
	*Winona County	5,000	20,000
	Winona Township	7,500	60,000
	Winona & Goodview	100,000	800,000
Pool 7	Minnesota DOT	8,000	64,000
	*Winona County	5,000	50,000
	New Hartford Twnshp.	400	4,000
	Dresbach City	300	3,000
	Dakota City	150	1,500
	Richmond Township	120	1,200
Pool 8	La Crosse County	125,000	1,000,000
	Shelby Township	12,500	190,000
	La Crosse City	43,750	700,000
	Campbell Township	1,250	30,000
	Onalaska Township	1,500	12,000
	Onalaska City	1,250	10,000
	*Vernon County	20,000	160,000
	Stoddard	875	6,000
	Bergen Township	5,000	50,000
	Minnesota DOT	40,000	320,000
	Houston County	37,500	300,000
	Brownsville	625	5,000
	Hokah Township	875	20,000
	La Crescent Village	750	6,000
Pool 9	*Vernon County	20,000	160,000
	Genoa Township	4,000	32,000
	Wheatland Township	3,000	24,000
	Genoa Village	400	3,200
	Victory	500	4,000
	*Crawford County	37,500	300,000
	Freeman Township	6,000	48,000
	Seneca Township	3,500	32,000
	Ferryville	10,000	800,000
	De Soto	600	5,000
	Lynxville	15,000	180,000
	Wisconsin DOT	290,000	700,000
	Allamakee	13,500	126,000
	New Albin	650	6,000
	Lansing	2,000	16,000

List of surveyed potential users of dredged materials and their demand (cont)

Pool	User	1981-1985 Short-term demand (cubic yards) for dredged material (all uses)	1986-2025 Long-term demand (cubic yards) for dredged material (all uses)
Pool 10	Clayton County	21,300	170,000
	Guttenburg	1,500	312,000
	Garnavillo	500	4,000
	Clayton	200	1,600
	Marquette	900	172,000
	Harpers Ferry	200	1,600
	Mc Gregor	1,100	358,400
	Grant County	6,500	52,000
	Wyalusing	800	6,000
	Bagley	300	2,000
	Bloomington	1,000	8,000
	Glen Haven	800	6,000
	*Crawford County	37,500	300,000
	Prairie du Chien	2,500	20,000
	Prairie du Chien	4,800	248,400



C. DREDGING REQUIREMENTS

FOREWORD

This appendix has been prepared by the Great River Environmental Action Team (GREAT I) Dredging Requirements Work Group cochairman and has not yet been reviewed by the GREAT I Team. Therefore, the opinions and recommendations stated in this draft report do not necessarily reflect the views and recommendations of GREAT I or any of the agencies associated with GREAT I.

SUPPLEMENT TO THE

DREDGING REQUIREMENTS WORK GROUP APPENDIX

UPDATED CONTRACT EFFORT AND RESULTS AS OF JULY 1980

A. General

This supplement updates the results of contract efforts that were in progress when the Dredging Requirements Work Group Appendix was being written.

B. Chippewa and Mississippi River Confluence Physical Model

The University of Minnesota is performing additional runs on the model. The final report should be completed in fall 1980. No results beyond those in the Dredging Requirements Work Group Appendix are available.

C. Two-Dimensional Mathematical Model of Lower Pool 4

General. - This contract has been completed. Volume I, Model Development and Calibration, is discussed in Section XII of the Dredging Requirements Work Group Appendix and is unchanged. Volume II, Model Application, was completed in November 1979. Volume II covers the application of the two-dimensional math model to lower pool 4 to assess impacts of various navigation channel maintenance and development works.

Development. - The model developed for lower pool 4 consisted of applying the two-dimensional math model to three subreaches of lower pool 4 and connecting these three subreaches via a one-dimensional math model of the entire lower pool 4 reach. A space interval of 80 feet was used to describe the channel bed in the three two-dimensional subreaches located near Read's Landing, Hershey (Crat's) Island, and Teepeeota Point. These subreaches were chosen because there is a history of maintenance dredging in these areas, and also because there is a considerable amount of cross-sectional data available for them. Persons interested in the computational methods used are referred to Volumes I and II.

Calibration. - The model was verified by using cross-sectional data available for lower pool 4 from 1 July 1974 to 30 June 1975. The model gave good general agreement with measured bed changes at Read's Landing. At Hershey (Crat's) Island, the model had difficulty in simulating the flow of water and sediment, probably because of the loss of flow to the west of Hershey Island. At Teepeeota Point, good general agreement was obtained.

Application. - To show the application of the two-dimensional model to study river problems, two examples consisting of evaluating the effects of a series of dikes at Read's Landing and a reduction in sediment discharge from the Chippewa River were examined. In both cases, the model was only run for 3 months (April-June 1975). Both the dike field and the reduction in sediment inflow had marked effects on the erosion and sedimentation patterns.

Conclusions. -

1. The coupled one-dimensional/two-dimensional water and sediment routing model appears to be well-suited to study problems of water and sediment flow in natural channels.

2. The two-dimensional models make possible the quantitative description of the movement of sandbars, the filling of sandbars, the local channel response to man-made structures, etc.

3. To get good resolution of bed changes, small time steps must be used. To allow the use of small time steps and still have a model that is cost-effective to run, a two-dimensional known discharge feature was used.

4. To get good results from the model, good field data, including high spatial resolution of initial geometry, flow velocities, and sediment transport data, are needed.

Recommendations. - Before this model should be used to determine channel responses to various dredging alternatives, extensive field data should be obtained to allow a detailed calibration and verification of the model. The initial bed geometry should be measured at the same resolution as the model (80-foot grid). Flow speed and direction and sediment transport data should be

obtained at the same resolution. Field velocity and sediment transport data at open boundaries are especially important. Also, the model should be properly documented and updated.

D. One-Dimensional Mathematical Model of Pools 5 Through 8

General. - The final report for this contract has been received (June 1980). The method used by the model is similar to that used for the one-dimensional math model study of pool 4 discussed in Section XII of the Dredging Requirements Work Group Appendix. However, the numerical scheme has been simplified somewhat by using an uncoupled implicit scheme rather than the simultaneous solution of the three governing equations used in the pool 4 model.

Development. - The total river reach was divided into smaller reaches, each one corresponding to one pool. Some of the reasons for this division are: the dams impose an effective artificial control for low flows, the model is simpler and the required computer storage is much less, it is easier to extend the model upstream or downstream, and local problems may be addressed in a simpler and more economical way. The model considers the effects of lateral flows and tributaries.

Calibration. - The calibration of the water routing in the model was accomplished using different Manning's numbers for the different reaches. The stages measured in 1965 and 1976 were reproduced at several locations, with good agreement. The sediment routing component of the model was calibrated by simulating the historical bed changes at several dredge cuts. The computed and measured changes were compared for the period of time beginning in July 1974 and ending in June 1975. Sediment calibration was only fair; closer results could have been obtained but given the accuracy of the input data it was not felt they would have been meaningful or worth the time spent on it.

<u>Application</u>. - The mathematical model was operated to assess amounts of sediment contributed by each major tributary and evaluate their effects on dredging requirements. The model was also used to consider the effect of dredging alternatives. These alternatives included overdredging in several spots, construction of dikes, reduction of sediment inflow from the Chippewa River, and closing of some outlets from the main channel to the Weaver Bottoms area in pool 5.

The total amount of bed material and wash load passing through each lock and dam and entering from each tributary was computed for two different flood events. The July 1974-June 1975 (10-year recurrence interval) and 1956 (2-year recurrence interval) floods were used.

Five alternatives were considered for pool 4: overdredging at Read's Landing, overdredging upstream of Teepeeota Point, construction of dikes at Read's Landing, construction of dikes upstream of Teepeeota Point, and reduction in sediment inflow from the Chippewa River. The following results were noted:

1. Overdredging at Read's Landing is not recommended because the reduction in deposition downstream of it is much smaller than the increase in dredging at Read's Landing. However, it would be interesting to study more years and different depths of overdredging.

2. Overdredging upstream of Teepeeota Point looks more attractive than overdredging at Read's Landing because, although there is a small increase in dredging volume, frequency is reduced.

3. Construction of dikes at Read's Landing and Teepeeota Point reduces the dredging requirement at these sites but increases it in the downstream cuts.

4. Reduction in the sediment inflow from the Chippewa River by 30 percent would eliminate dredging at Read's Landing in the near future. The reduction in sediment discharge downstream of Read's Landing would be partly compensated by erosion in the area between Read's Landing and Teepeeota Point. Therefore, it would take more than 3 years to notice the efforts at Teepeeota Point and downstream.

5. Effects of dredging alternatives in pool 4 on dredging requirement in downstream pools can be illustrated by the effects on volume of sediment transported from pool 4 to pool 5. Overdredging at Read's Landing and Teepeeota Point would have negligible effects on sediment volumes compared with volumes for normal dredging during the 10-year study period, but the effects could become significant after a longer time period. Dike construction at Read's Landing and Teepeeota Point would reduce dredging quantities in pool 4 by about 10 percent and increase sediment volume entering pool 5 by about 5 percent at the end of the 10-year study period. This would increase dredging quantity in pool 5 accordingly, but would cause a net reduction in combined dredging quantities in pools 4 and 5.

As a generalization of these conclusions, it may be said that overdredging is most interesting when the overdredged area is followed by other areas with frequent dredging requirement. On the other hand, construction of dikes is effective in sedimentation areas without frequent deposition immediately downstream of that area but could otherwise aggravate dredging problems. With a proper combination of overdredging and dike construction, it is possible to reduce overall dredging quantity. Longer model runs are required to evaluate the long-term impacts.

Conclusions. - Some of the conclusions obtained were:

1. Overdredging may be advantageous when other sedimentation areas are immediately downstream of the overdredged area. Otherwise, it is not recommended.

2. The situation is the opposite for dike construction.

3. Closure of outlets reduces the sediment deposition in the main channel.

4. Reduction of sediment inflow from the Chippewa River reduces the sedimentation near the confluence with the Mississippi River, but it takes several years to notice its effects several miles downstream because of the erosion provoked in some areas.

These alternatives can be further studied with the model by changing part of the data. The model can help determine the most appropriate location for dikes; the optimum depth of dredging; whether it is convenient to overdredge in one area every year or better to allow the bed level to reach the original level before it is overdredged again; the most convenient outlets to close; and, in general, the effect of any change in the river system.

The physical phenomenon cannot be represented with complete accuracy by a one-dimensional model because the prototype characteristics have to be simplified, but it is common for the one-dimensional model to obtain an acceptable level of accuracy by reducing the distance between the cross sections and the time step.

Because of the large number of branches and islands in the Upper Mississippi River, some sections have to be defined in a subjective way. In general, data were not sufficient and some assumptions had to be made. The model would be more effective if better data about the effects of dikes, the concentration of sediment in branches and outlets, and the transport of sediment were available for every reach.

Some computational difficulty may arise because of the difference in size between the Mississippi River and the tributaries. This can lead to instability in the solution of the bed levels, if the time step or the amount of sediment allowed to accumulate before computation of new cross-sectional geometries is too large.

The effect of submerged dikes in the sediment routing is difficult to simulate because they impose low velocities in the water flowing above them for low discharges, but allow velocities close to the ones in the main channel at high flow. A possible way of solving this problem would be to compute the sediment transport for every subsection within a section instead of using the average velocity. The model would be more complex and the required computer time larger, but it may be worthwhile.

More data, mostly cross-sectional geometries, are necessary for a detailed study of pools other than pool 4. The more and better data used in the model, the more precise results can be obtained.

Recommendations. - The one-dimensional mathematical model appears to be the most cost-effective method for quantifying the effects of dredging alternatives on downstream reaches and for long terms and is recommended for this. Local, short-term effects can be predicted more accurately with the two-dimensional model or a physical model. Before the one-dimensional model is used to obtain final results, more data and a better calibration are needed.

E. Strip Version of HEC-6.

This model was not successfully calibrated as of June 1980. Mr. William A. Thomas of the U.S. Army Engineers Waterways Experiment Station is working on the model with funds provided by other sources.

SYNOPSIS

The purpose of the Dredging Requirements Work Group was to develop criteria for maintenance dredging to minimize the total dredging quantities without loss of the integrity of the 9-foot channel and to investigate sediment traps, structural modifications, pool regulation, and navigational aid application to reduce dredging and/or material placement impact.

The work group identified the following factors which affect dredging quantity:

1. Hydrology and sediment transport capability.
2. Dredging depth.
3. Navigational channel width.
4. Channel alignment.
5. Channel longevity (dredging frequency).
6. Tributary sediment supply.
7. Wing dam and closing dam design.
8. Dredged material placement.
9. Channel condition initiating maintenance.
10. Pool levels.
11. Navigational use impacts.
12. Navigation aid location.

Many of these factors are interrelated. For example, if the depth of dredging varies, it will potentially affect quantity of dredging, frequency of dredging, dredging equipment needs, channel reliability, required channel width for navigation, dredged material placement site capability, commercial transport cost, dredging cost, environmental impact and navigational safety. This complex interrelationship and the scope of work involving maintenance of 284 miles of channel at 122 separate historic channel maintenance sites with an average annual dredging requirement of 1.52 million cubic yards posed a definite challange.

Three basic methods of investigation were identified and pursued: field prototype testing, physical modeling, and mathematical modeling. Because of cost and time limitations, the field and physical models were used to develop mathematical models which could potentially be applied throughout the system to best define optimum dredging parameters, structural modification, pool regulation, and sediment trap siting to minimize dredging quantity.

Modification of dredging parameters was accomplished at 33 field test sites during the GREAT program (1975-1978) resulting in a 34.5 percent decrease in dredging quantity. Although the overall impact on frequency was an unacceptable 34.1 percent increase, if the individual sites are analyzed, 18 sites were very successful. These 18 sites had no increase in frequency of dredging with a 67.5 percent decrease in dredging quantity. The other 15 sites had a dredging

frequency increase of 77.1 percent with a dredging quantity decrease of 19.6 percent. This illustrates that the dredging quantity can be reduced significantly, but dredging parameters must be established for each site through application of technically-supported criteria.

Dredging width was tentatively established through a survey of highly qualified pilots. Overall historic width on channel bends was slightly reduced. A committee should be established to review channel dimensions. The committee should include qualified representatives from the Corps of Engineers, Coast Guard, navigation industry, and concerned States and other Federal agencies. The depth of dredging and channel width relationships should be investigated further.

A physical model was constructed of the Mississippi-Chippewa Rivers confluence by contract with the University of Minnesota. The significant findings have been used to calibrate the mathematical models and document that a sediment trap in the Chippewa River delta would be very effective in reducing dredging requirements in the Mississippi River.

Mathematical models were developed by contract with Colorado State University. A one-dimensional model was established for the Mississippi River from lock and dam 8, Genoa, Wisconsin, to Lake Pepin, above Reads Landing, Minnesota.

A two-dimensional model was developed for potential deployment at individual dredging sites. This model has been calibrated for the Reads Landing, Minnesota, dredging site but requires further calibration before general application.

The one-dimensional math model should be completed for the entire reach for definition of the sediment transport through the system and as a basis for selecting individual site dredging parameters before refinement of the two-dimensional model. If feasible, the two-dimensional math model should be applied to all significant dredging sites to select optimum dredging parameters, identify site specific wing dam and closing dam modifications, identify viable sediment traps, and evaluate riverine placement of dredged material.

Dredging quantities have been significantly reduced, but a challenge remains to refine and continue to implement this effort.

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Comparison Between the Calculated and Measured Amount of Sediment Deposited in Dredge Cut (Figure 10) 114

DREDGING REQUIREMENTS
WORK GROUP APPENDIX

I. PURPOSE

The Dredging Requirements Work Group (DRWG) defined its problem as follows:

> Average annual dredging requirements of 1.52 million cubic yards (1956-1974) are presently accomplished for maintenance of the Mississippi River 9-Foot Channel System above Guttenberg, Iowa. This large quantity of material places excessive demand on the available beneficial-use sites within the floodplain, results in environmental degradation, and makes alternative disposal methods very costly.

To reduce this problem, the following DRWG purpose was established:

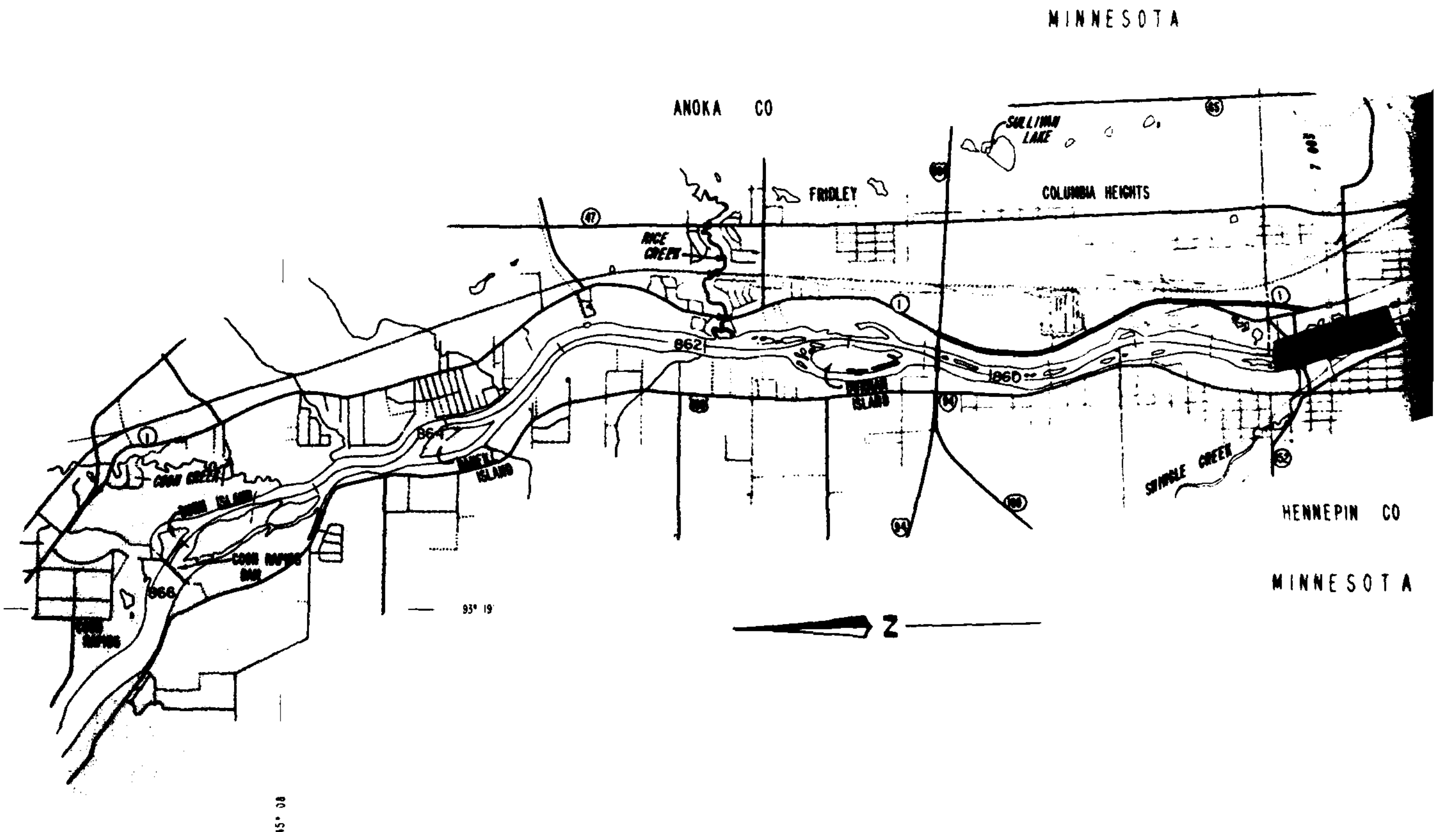
> To develop recommended criteria for maintenance dredging parameters to minimize the total dredging quantities without loss of the integrity of the 9-foot channel allowing an exception for bed load traps which might prove beneficial, and to investigate structural, pool regulation, and navigational aid alternatives to minimize dredging requirements.

II. RECENT CHANNEL MAINTENANCE HISTORY

The St. Paul District maintains 284.2 miles of the 9-foot channel on the Mississippi, Minnesota, St. Croix and Black Rivers. Maps 1-8 illustrate the individual site average dredging requirements. Graph

U S DEPARTMENT OF AGRICULTURE

POOL 1 90,000 Cubic Yards = 56 Acre Feet



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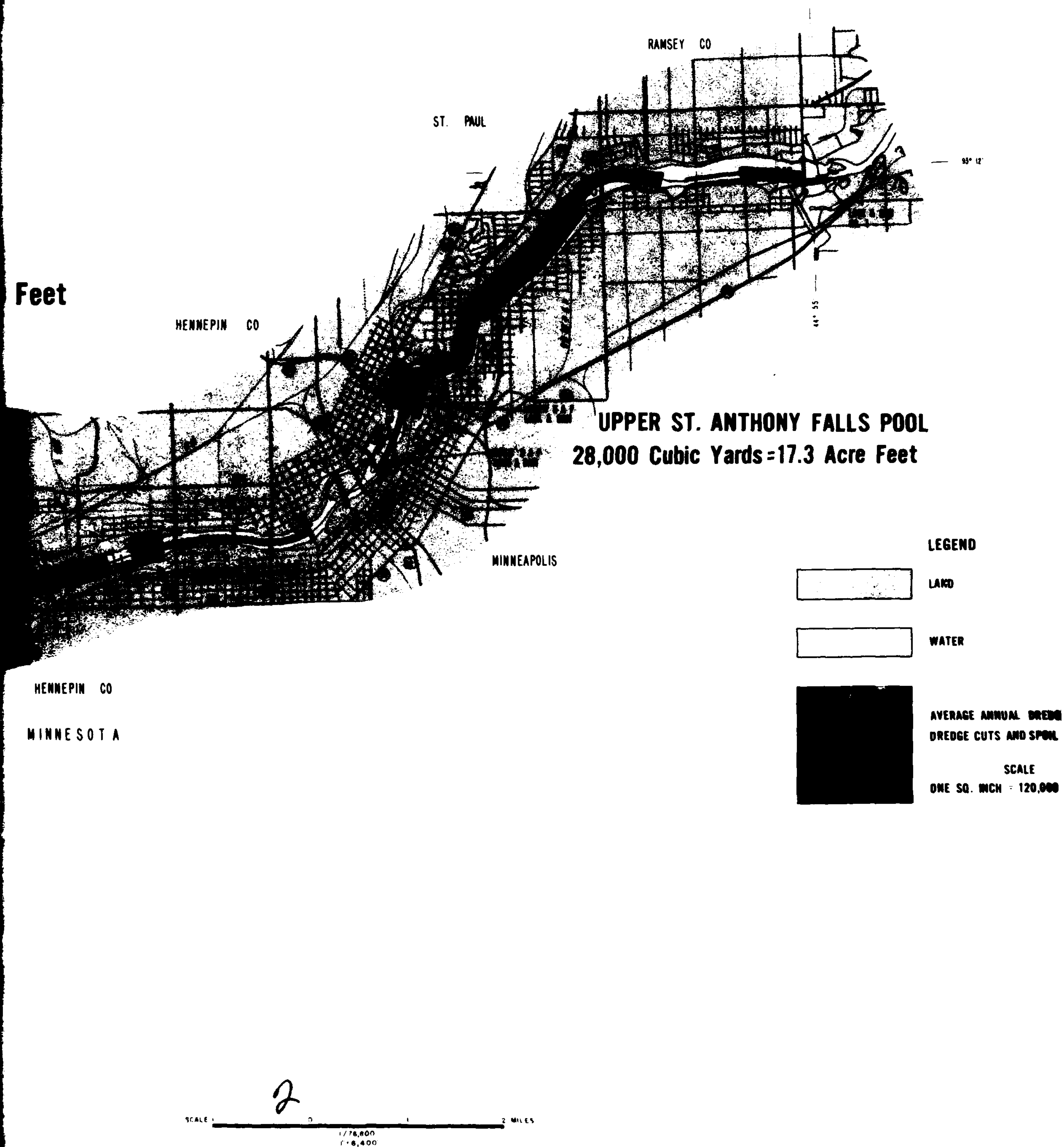
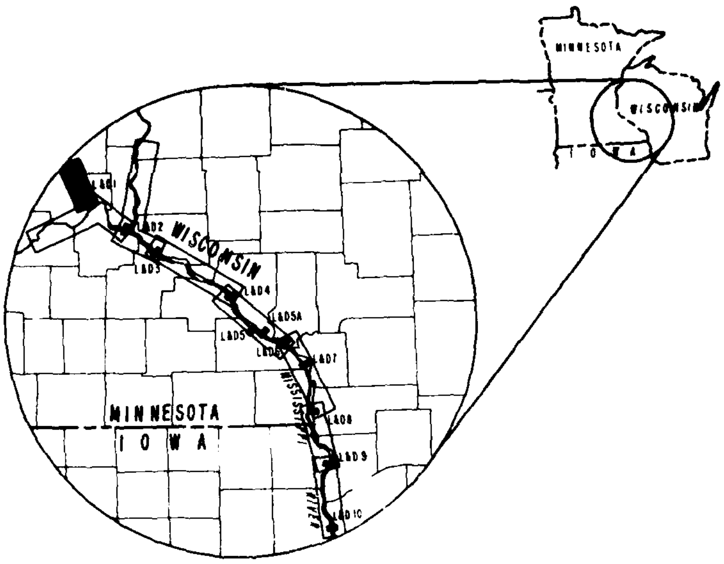


Feet
RAMSEY CO
ST. PAUL
HENNEPIN CO
MINNEAPOLIS
HENNEPIN CO
MINNESOTA
UPPER ST. ANTHONY FALLS POOL
28,000 Cubic Yards=17.3 Acre Feet
LEGEND
LAND
WATER
AVERAGE ANNUAL
DREDGE CUTS AND SPOIL
SCALE
ONE SQ. INCH = 120,000
SCALE 1 0 1 2 MILES
1/76,800

2

— 93° 12'



LLS POOL
cre Feet

LEGEND

LAND

WATER

AVERAGE ANNUAL DREDGING (1956 - 1974)
DREDGE CUTS AND SPOIL DEPOSITS

SCALE
ONE SQ. INCH = 120,000 CU. YDS = 74 ACRE FEET

AVERAGE ANNUAL DREDGING VOLUME AND LOCATION MAP

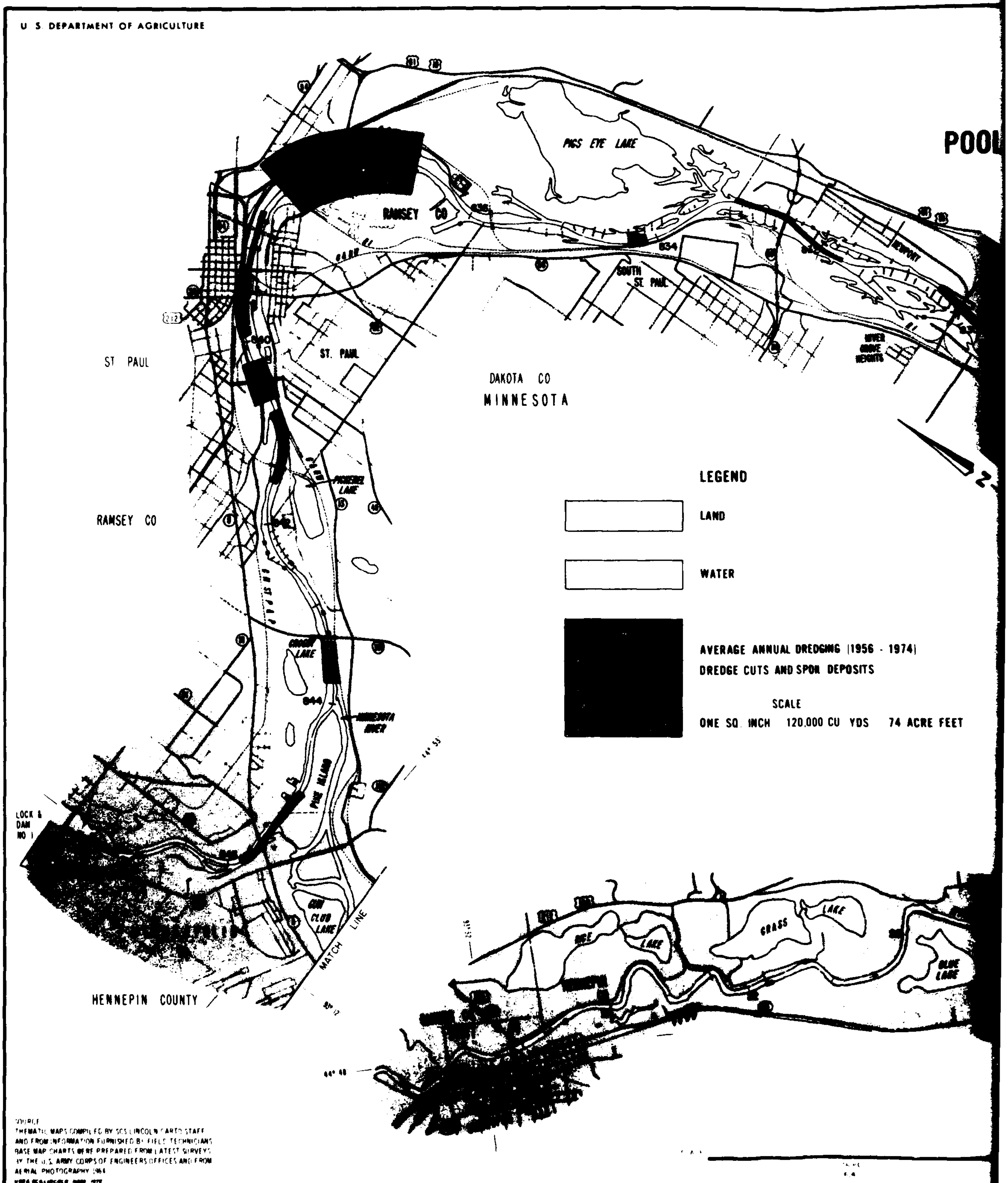
GREAT I

UPPER MISSISSIPPI RIVER BASIN

IOWA, MINNESOTA, SOUTH DAKOTA AND WISCONSIN

3

2-20-78
S,R-36,603



U S DEPARTMENT OF AGRICULTURE
POOL
PIGS EYE LAKE
RAMSEY CO
SOUTH ST PAUL
NEWPORT
RIVER GROVE HEIGHTS
ST PAUL
ST. PAUL
DAKOTA CO
MINNESOTA
RAMSEY CO
PICKEREL LAKE
CROSBY LAKE
MINNESOTA RIVER
PIKE ISLAND
LOCK & DAM NO 1
GUN CLUB LAKE
MATCH LINE
HENNEPIN COUNTY
RICE LAKE
GRASS LAKE
BLUE LAKE
LEGEND
LAND
WATER
AVERAGE ANNUAL DREDGING (1956 - 1974)
DREDGE CUTS AND SPOIL DEPOSITS
SCALE
ONE SQ. INCH 120,000 CU YDS 74 ACRE FEET
SOURCE
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AND FROM INFORMATION FURNISHED BY FIELD TECHNICIANS
BASE MAP CHARTS WERE PREPARED FROM LATEST SURVEYS
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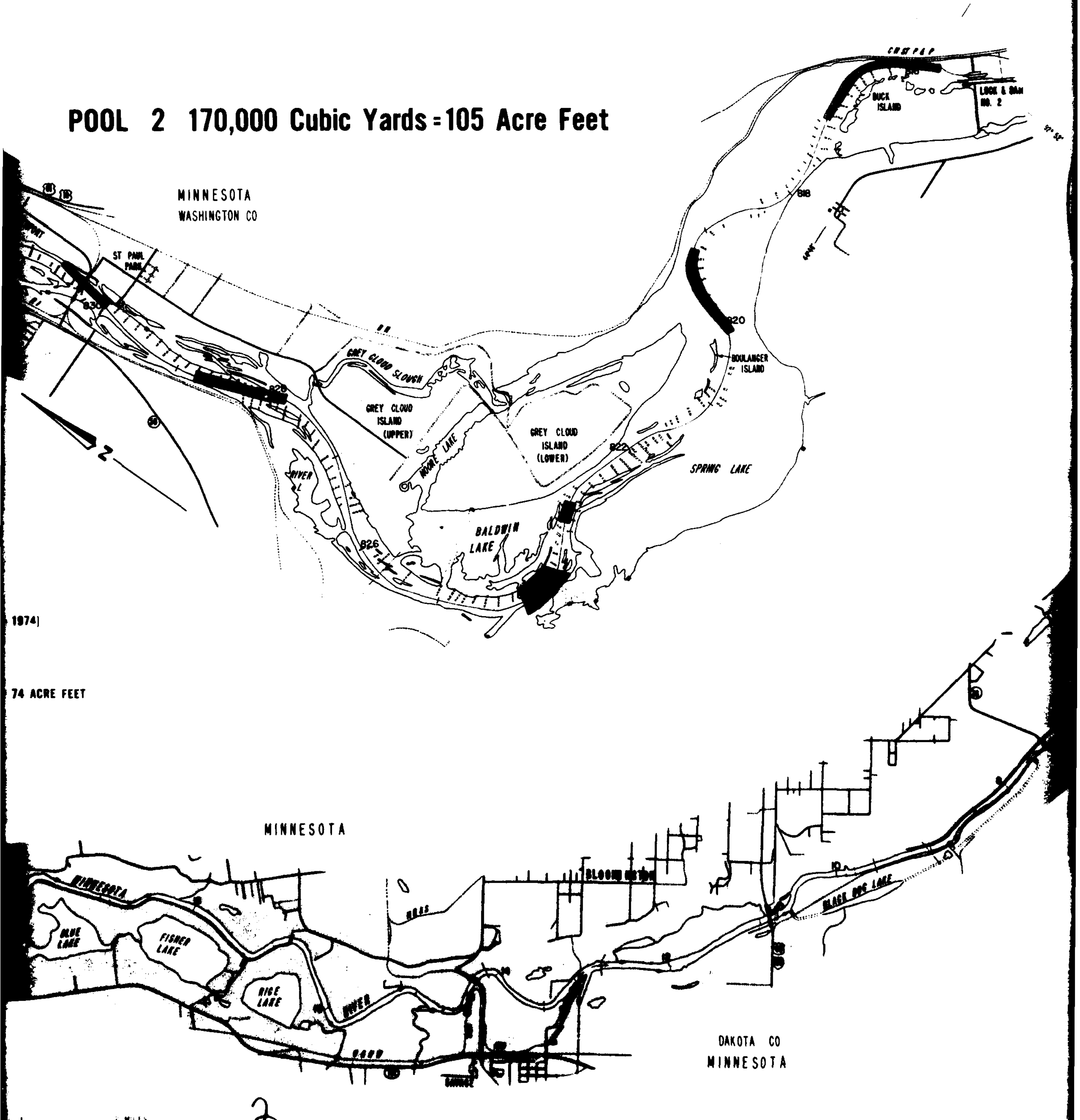
POOL 2 170,000 Cubic Yards = 105 Acre Feet



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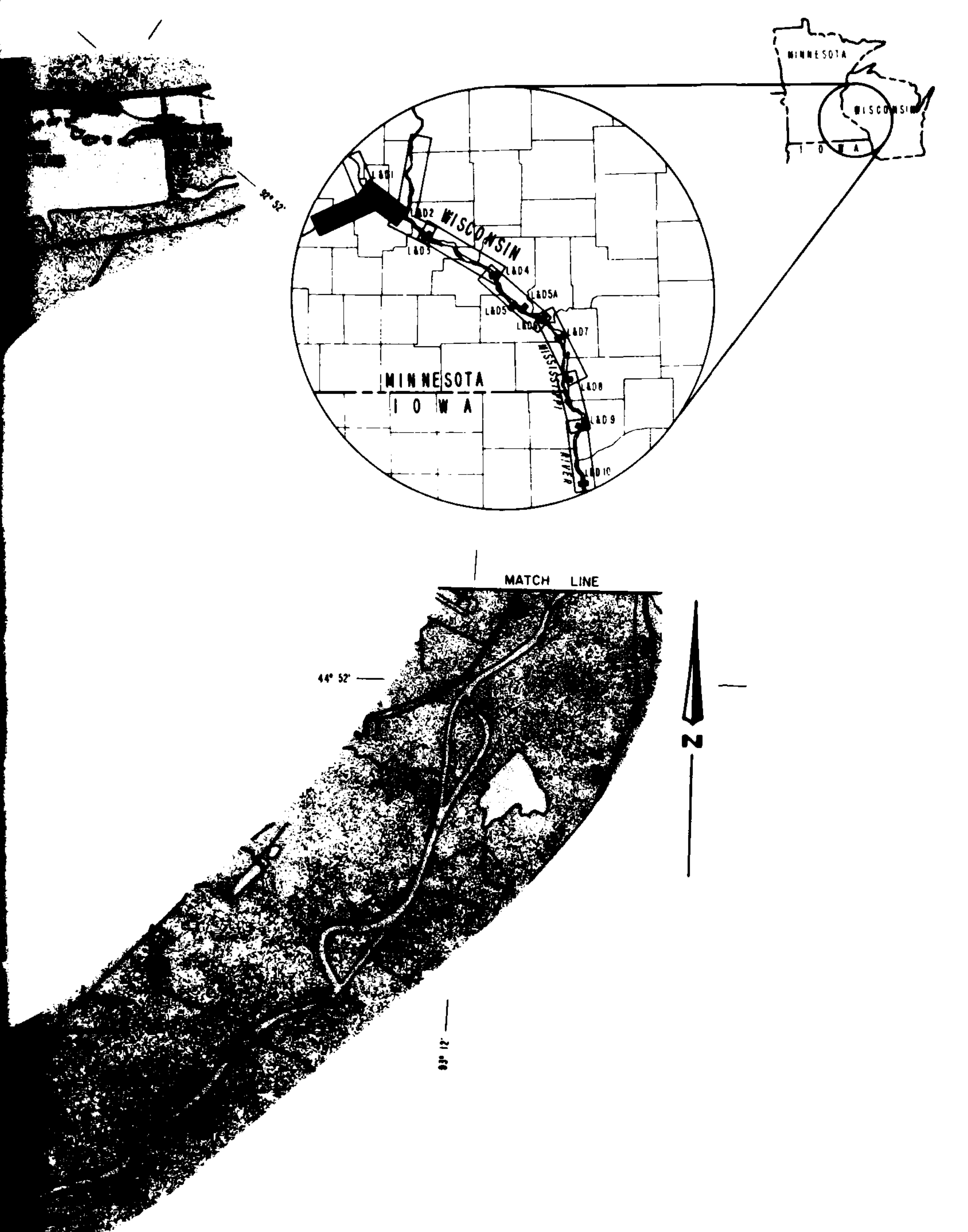


AVERAGE ANNUAL DREDGING VOLUME AND LOCATION MAP

GREAT I

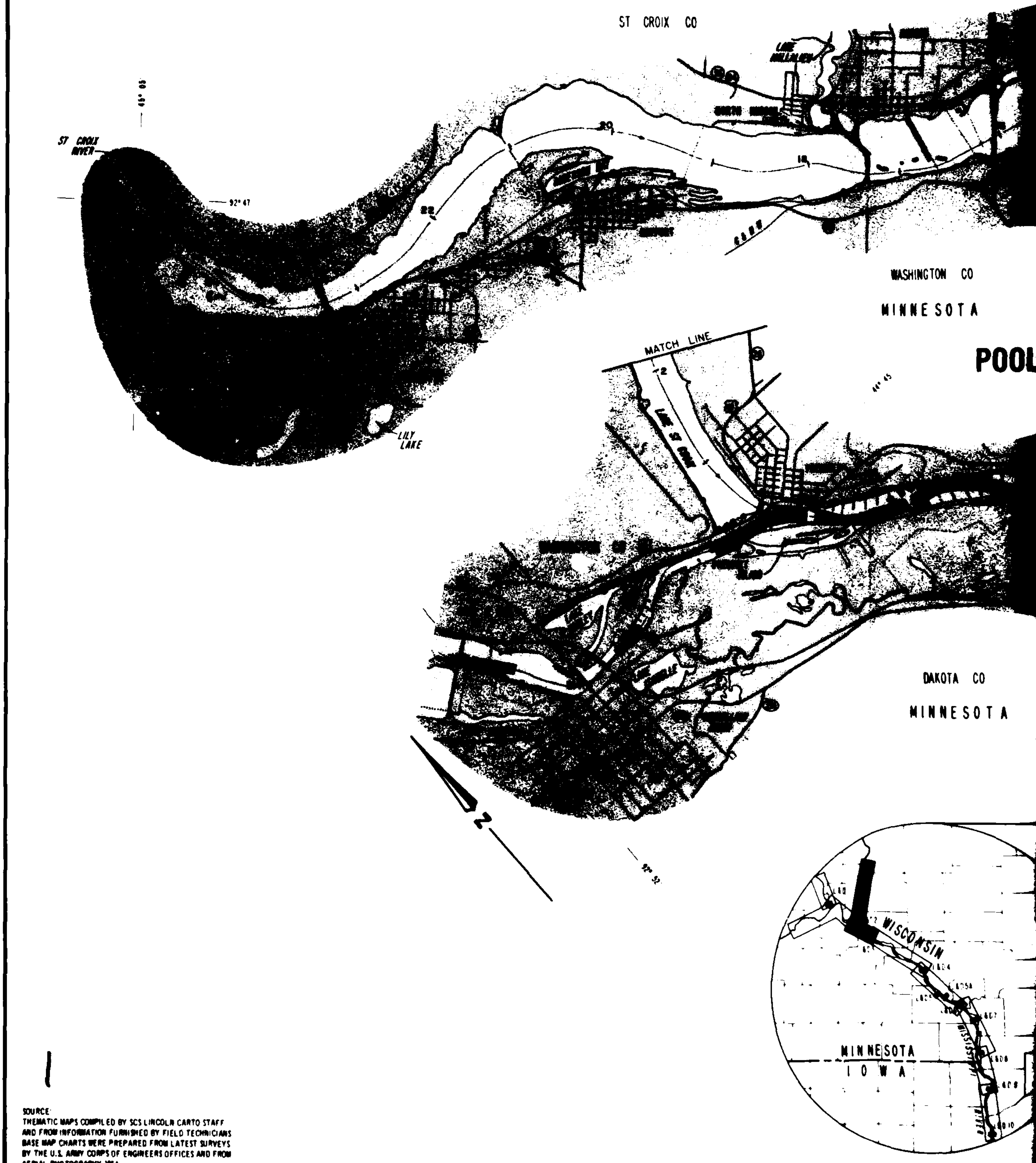
UPPER MISSISSIPPI RIVER BASIN

IOWA, MINNESOTA, SOUTH DAKOTA AND WISCONSIN

3

2-20-78
5,R-36,604

U. S. DEPARTMENT OF AGRICULTURE



SOURCE:
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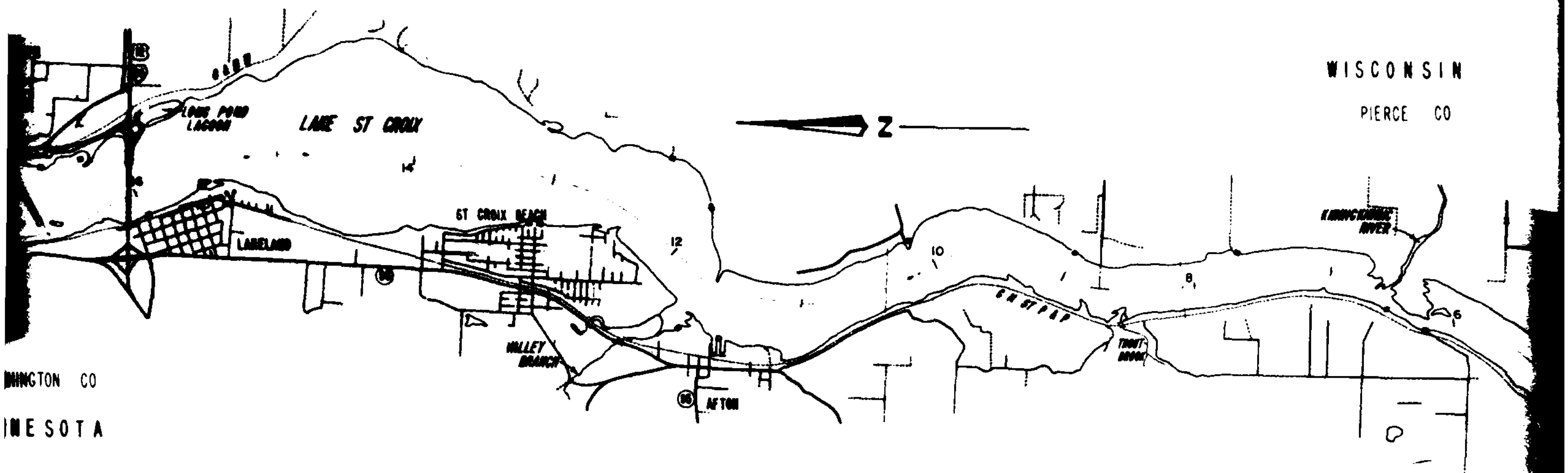
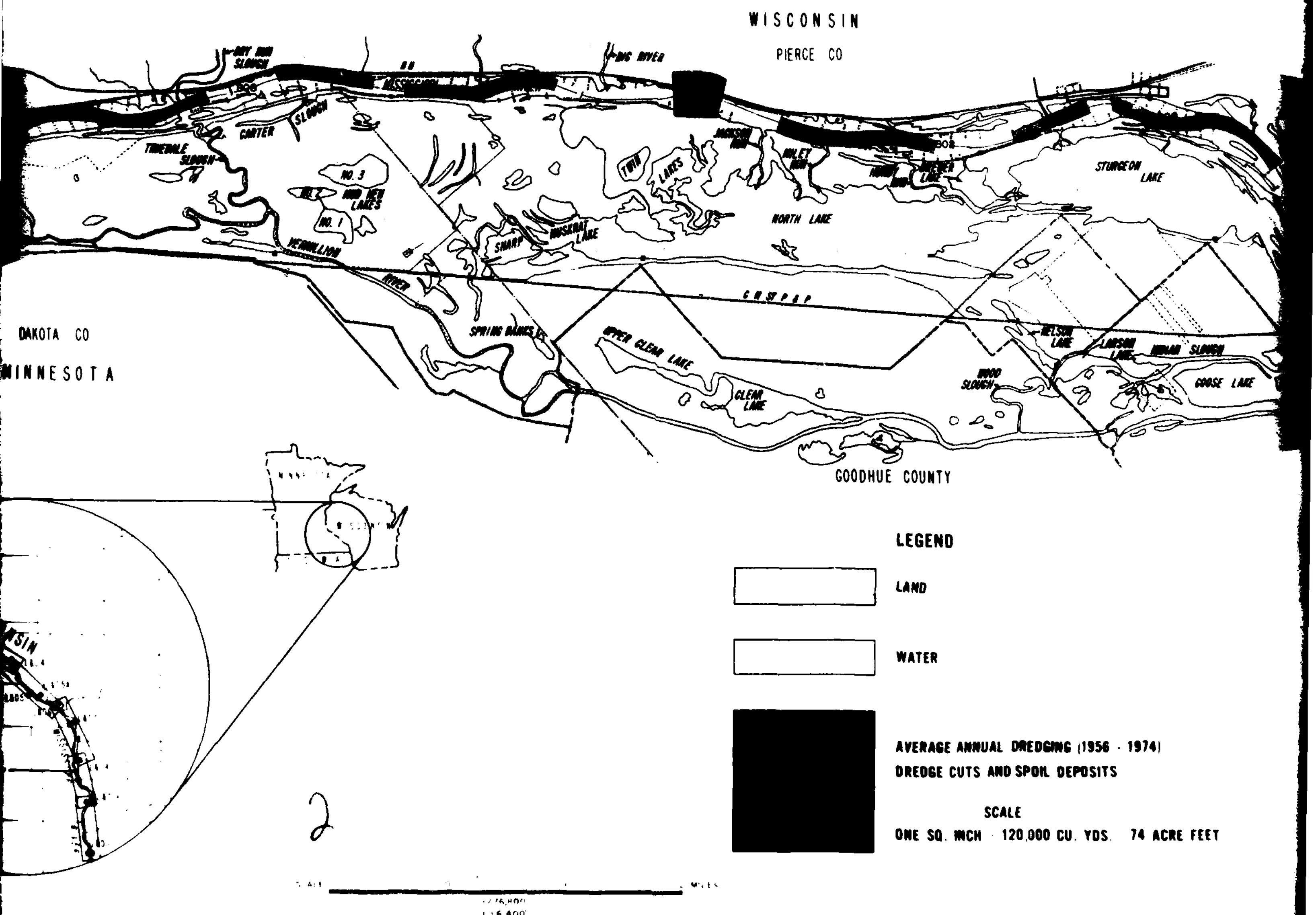


POOL 3 100,000 Cubic Yards = 62 Acre Feet



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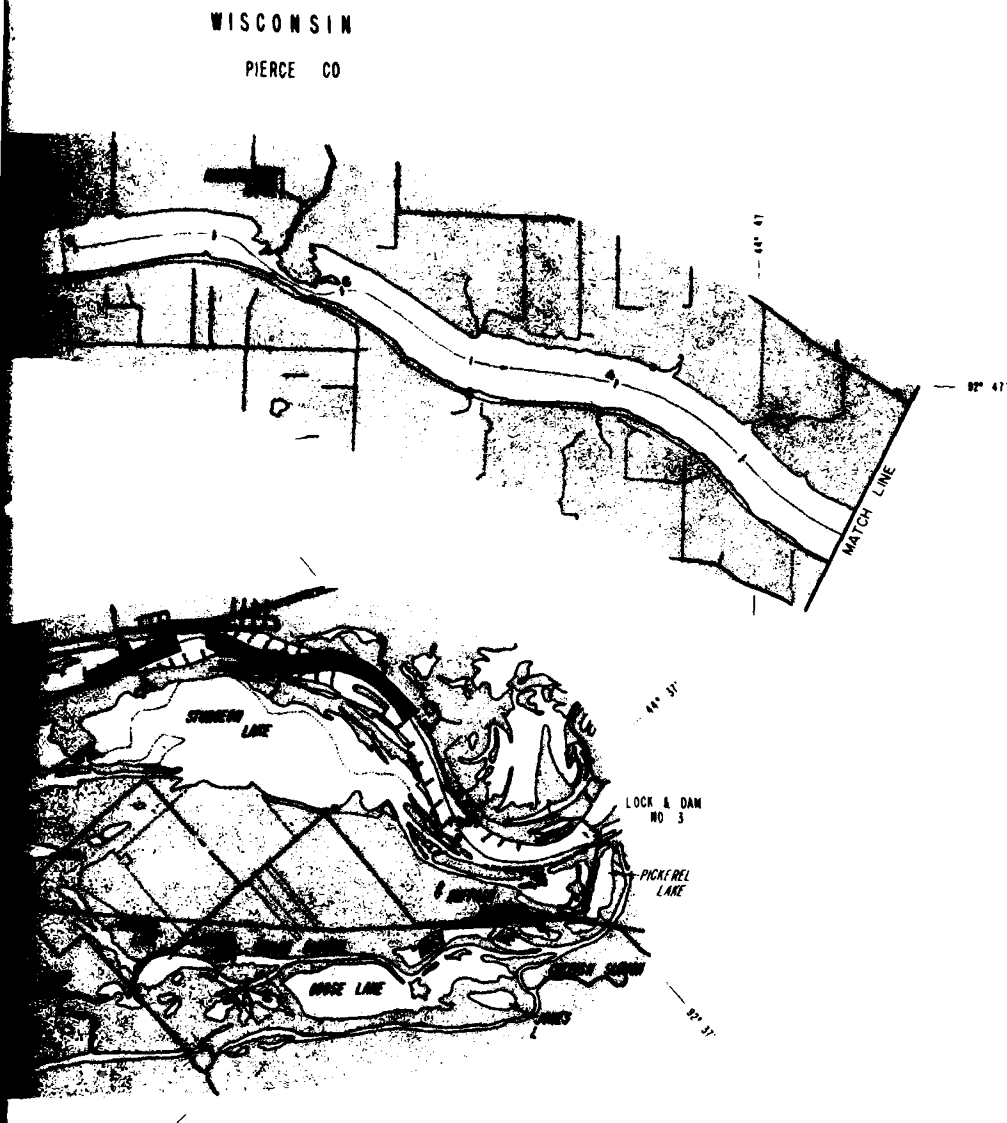


ANNUAL DREDGING (1956 - 1974)
CUTS AND SPOIL DEPOSITS

SCALE
NCH = 120,000 CU. YDS. = 74 ACRE FEET

AVERAGE ANNUAL DREDGING VOLUME AND LOCATION MAP

GREAT I

UPPER MISSISSIPPI RIVER BASIN

IOWA, MINNESOTA, SOUTH DAKOTA AND WISCONSIN

3

2-20-78
5,R-36,605

U. S. DEPARTMENT OF AGRICULTURE

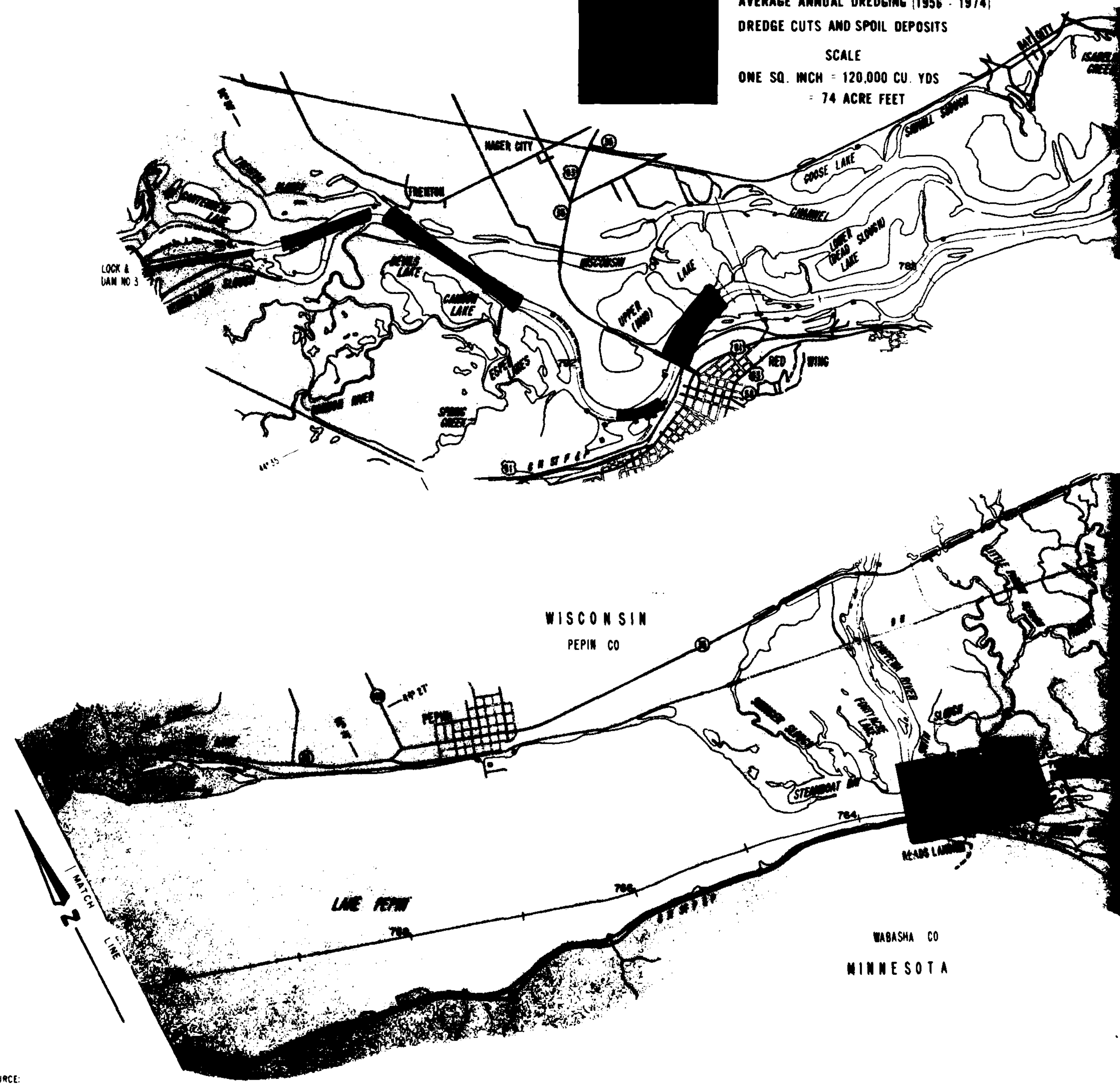
LEGEND

LAND

WATER

AVERAGE ANNUAL DREDGING (1956 - 1974)
DREDGE CUTS AND SPOIL DEPOSITS

SCALE
ONE SQ. INCH = 120,000 CU. YDS
= 74 ACRE FEET



SOURCE:
THEMATIC MAPS COMPILED BY SCS LINCOLN CARTO STAFF
AND FROM INFORMATION FURNISHED BY FIELD TECHNICIANS
BASE MAP CHARTS WERE PREPARED FROM LATEST SURVEYS
BY THE U.S. ARMY CORPS OF ENGINEERS OFFICES AND FROM
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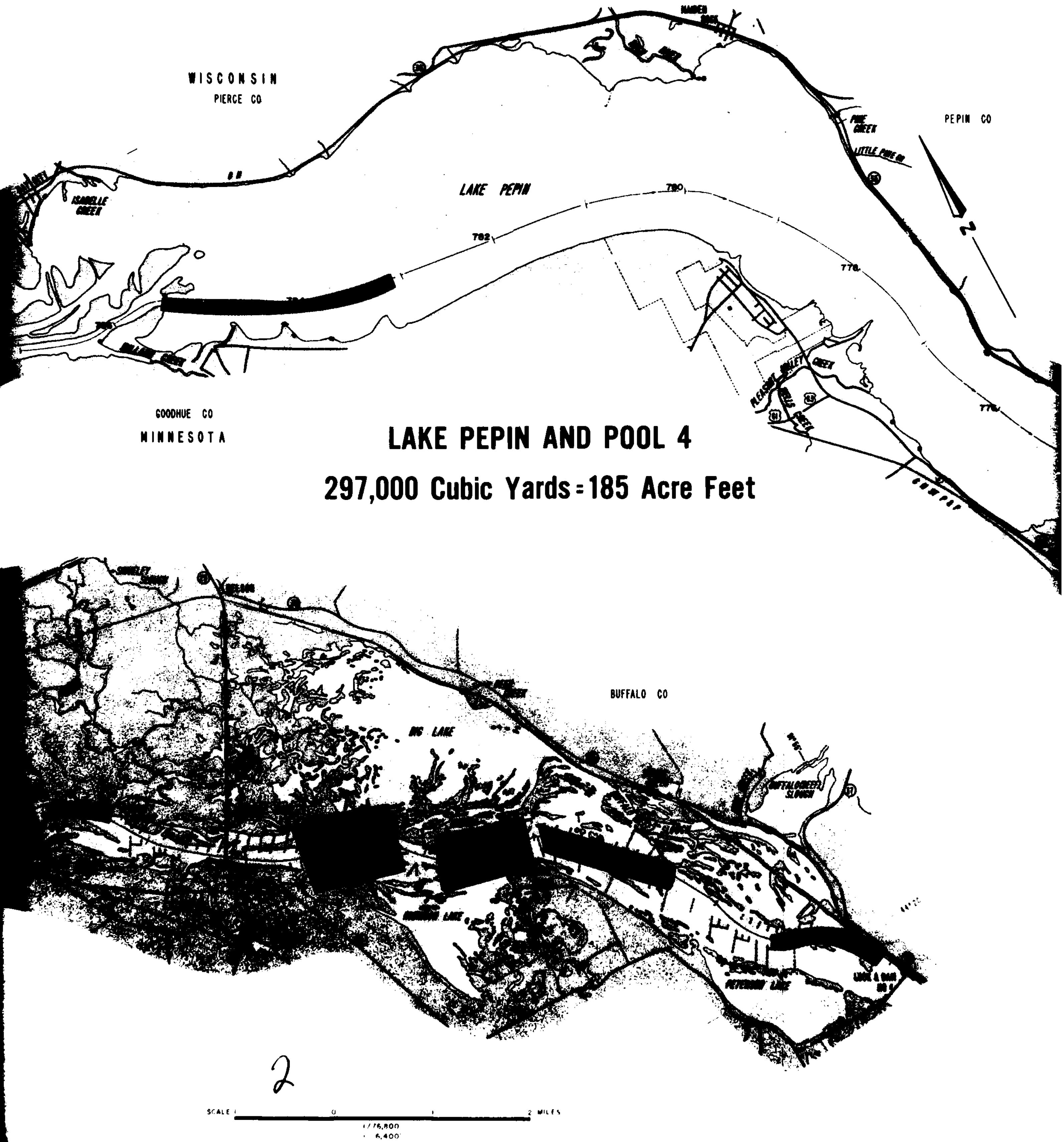
LAKE PEPIN AND POOL 4

297,000 Cubic Yards = 185 Acre Feet



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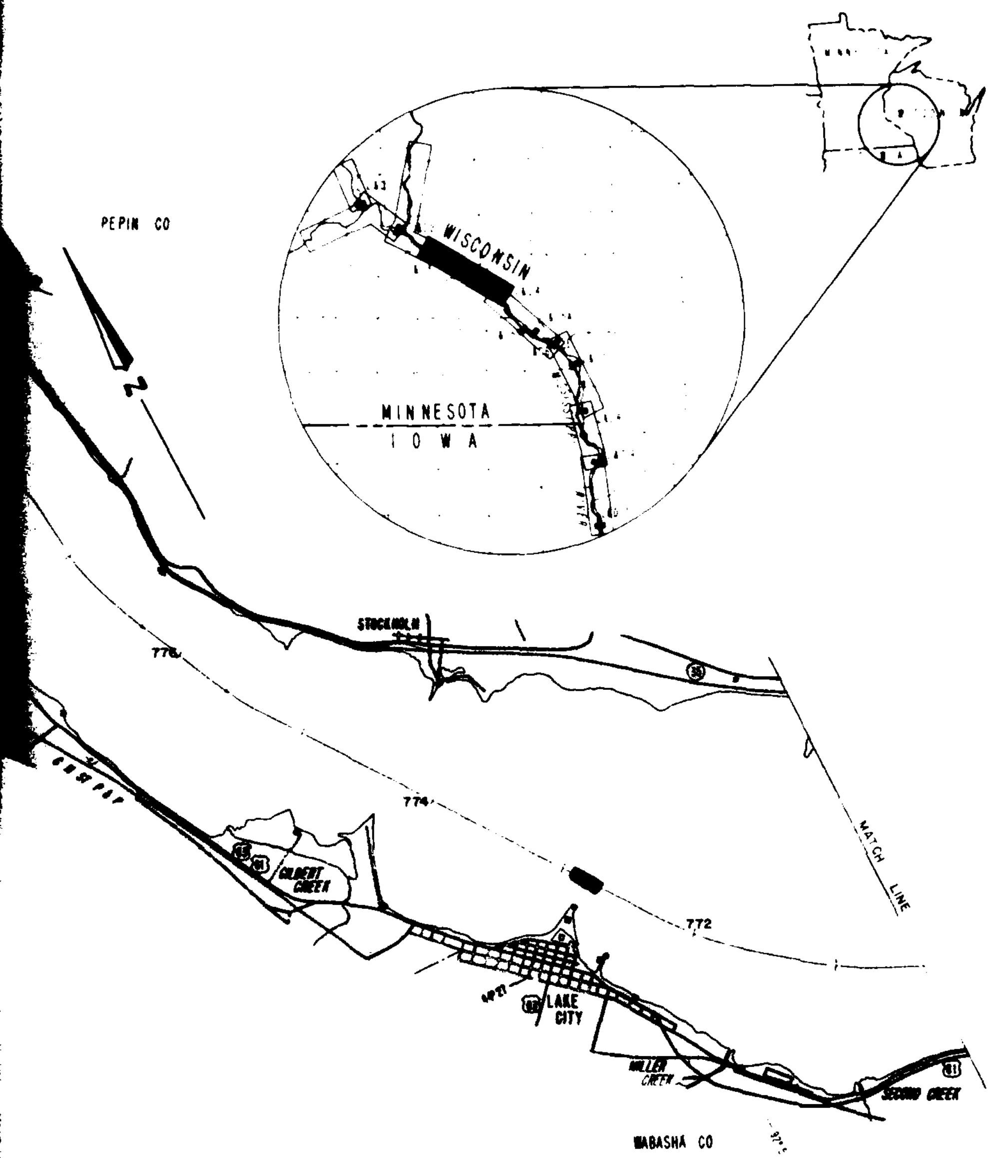

AVERAGE ANNUAL DREDGING VOLUME AND LOCATION MAP

GREAT I

UPPER MISSISSIPPI RIVER BASIN

IOWA, MINNESOTA, SOUTH DAKOTA AND WISCONSIN

3

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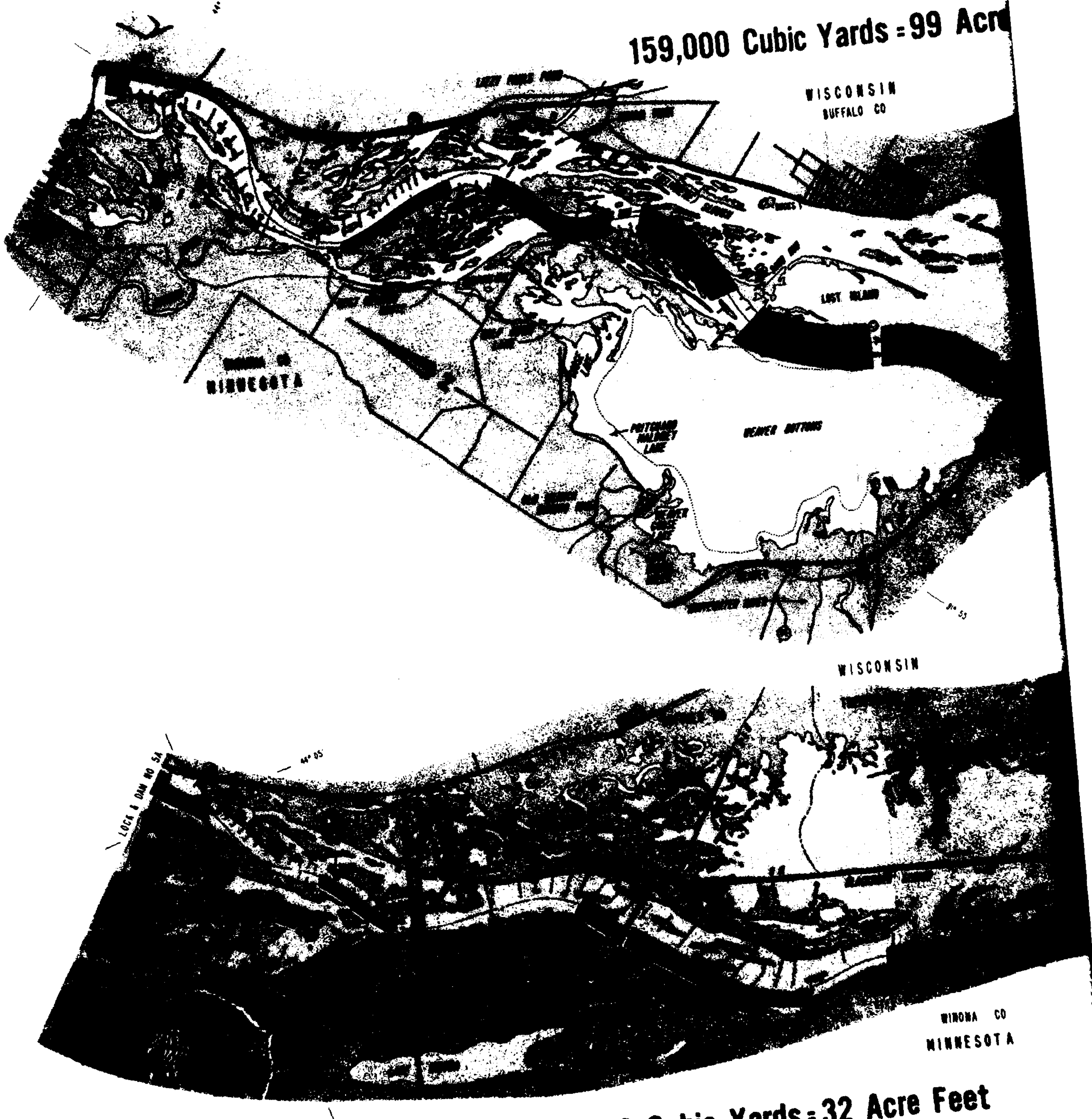
5,R-36,606

U S DEPARTMENT OF AGRICULTURE

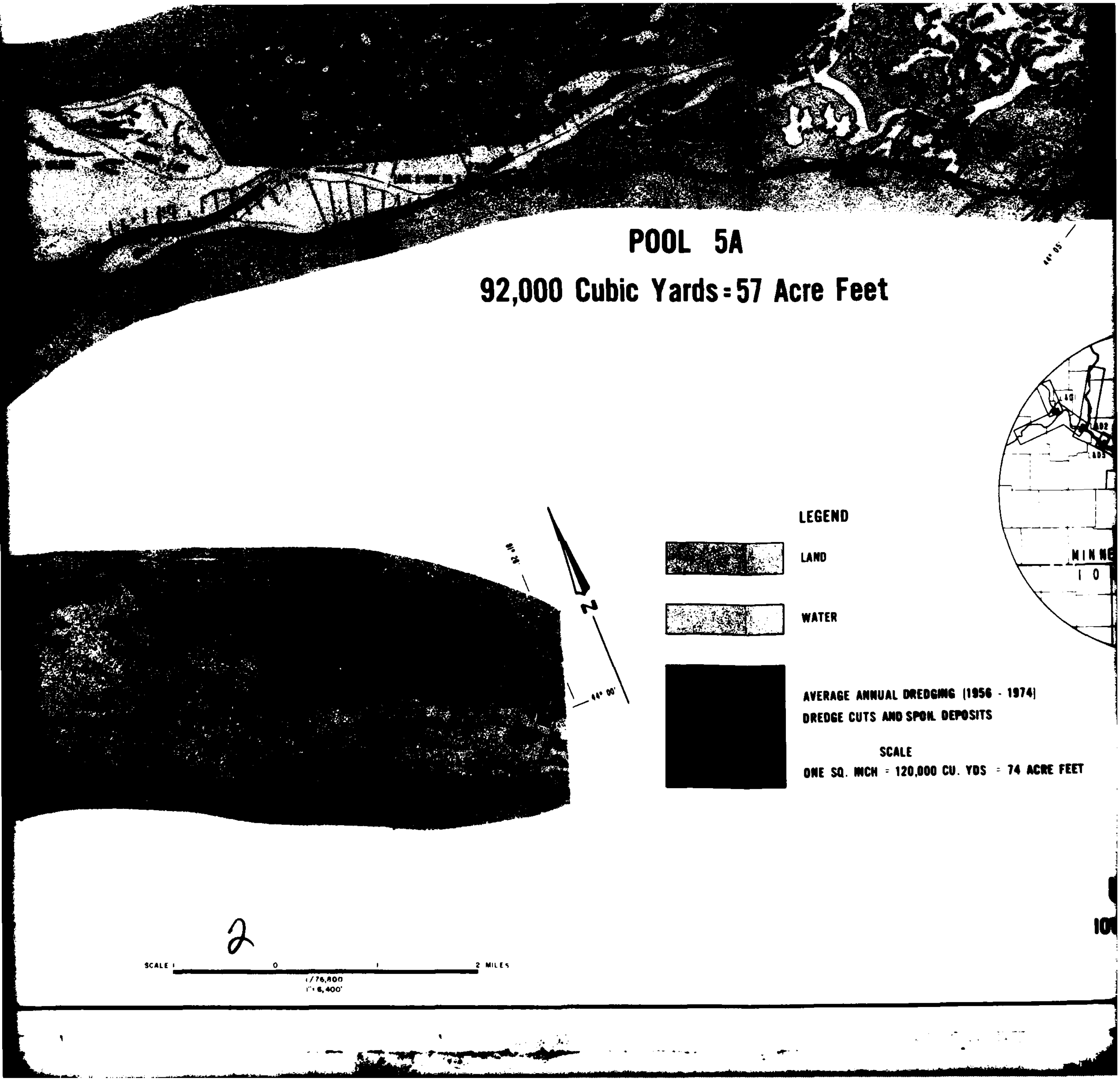
POOL 5

159,000 Cubic Yards = 99 Acr

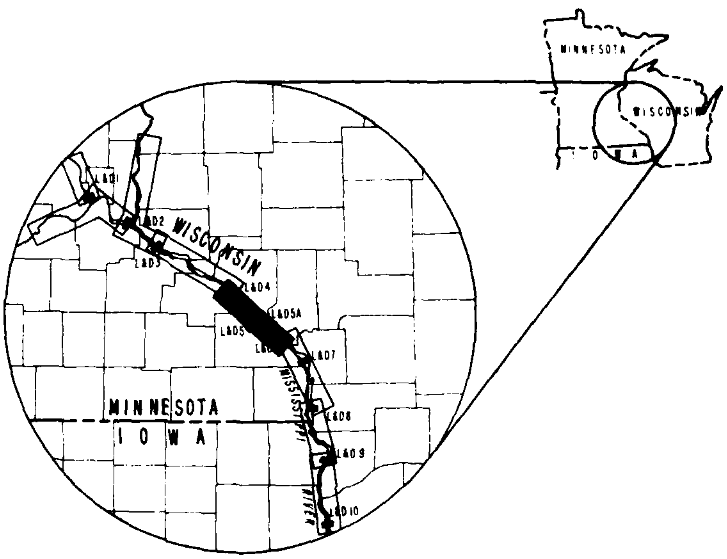


POOL 6 52,000 Cubic Yards = 32 Acre Feet

SOURCE:
THEMATIC MAPS COMPILED BY SCS LINCOLN CARTO STAFF AND FROM INFORMATION FURNISHED BY FIELD TECHNICIANS
BASE MAP CHARTS WERE PREPARED FROM LATEST SURVEYS BY THE U.S. ARMY CORPS OF ENGINEERS OFFICES AND FROM AERIAL PHOTOGRAPHY 1964


POOL 5A
92,000 Cubic Yards = 57 Acre Feet
LEGEND
LAND
WATER
AVERAGE ANNUAL DREDGING (1956 - 1974)
DREDGE CUTS AND SPOIL DEPOSITS
SCALE
ONE SQ. INCH = 120,000 CU. YDS = 74 ACRE FEET
2
SCALE 1 0 1 2 MILES
1/76,800
1" = 6,400'

Feet



END

ER

ERAGE ANNUAL DREDGING (1956 - 1974)
EDGE CUTS AND SPOIL DEPOSITS

SCALE
SQ. INCH = 120,000 CU. YDS = 74 ACRE FEET

AVERAGE ANNUAL DREDGING VOLUME AND LOCATION MAP

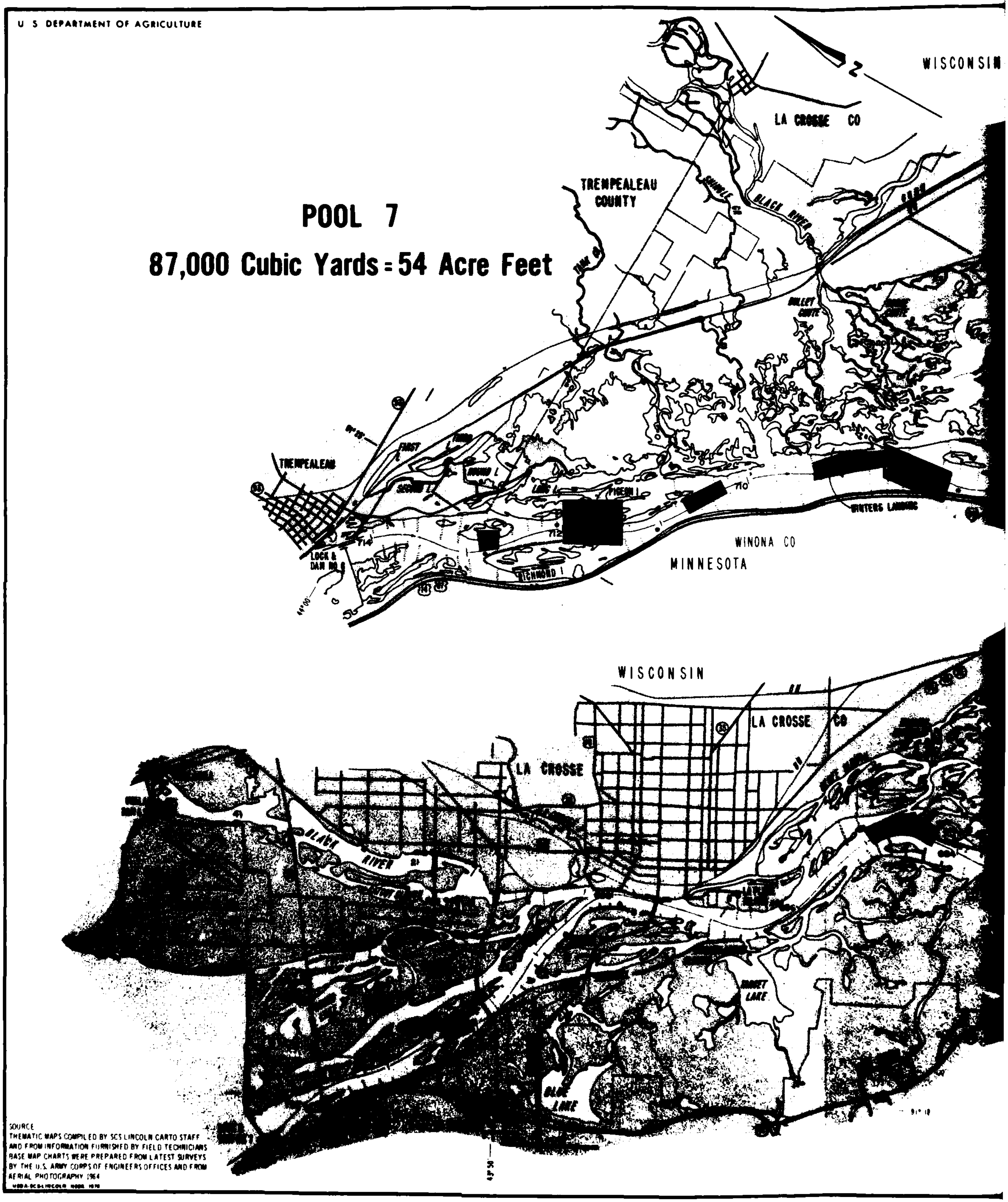
GREAT I

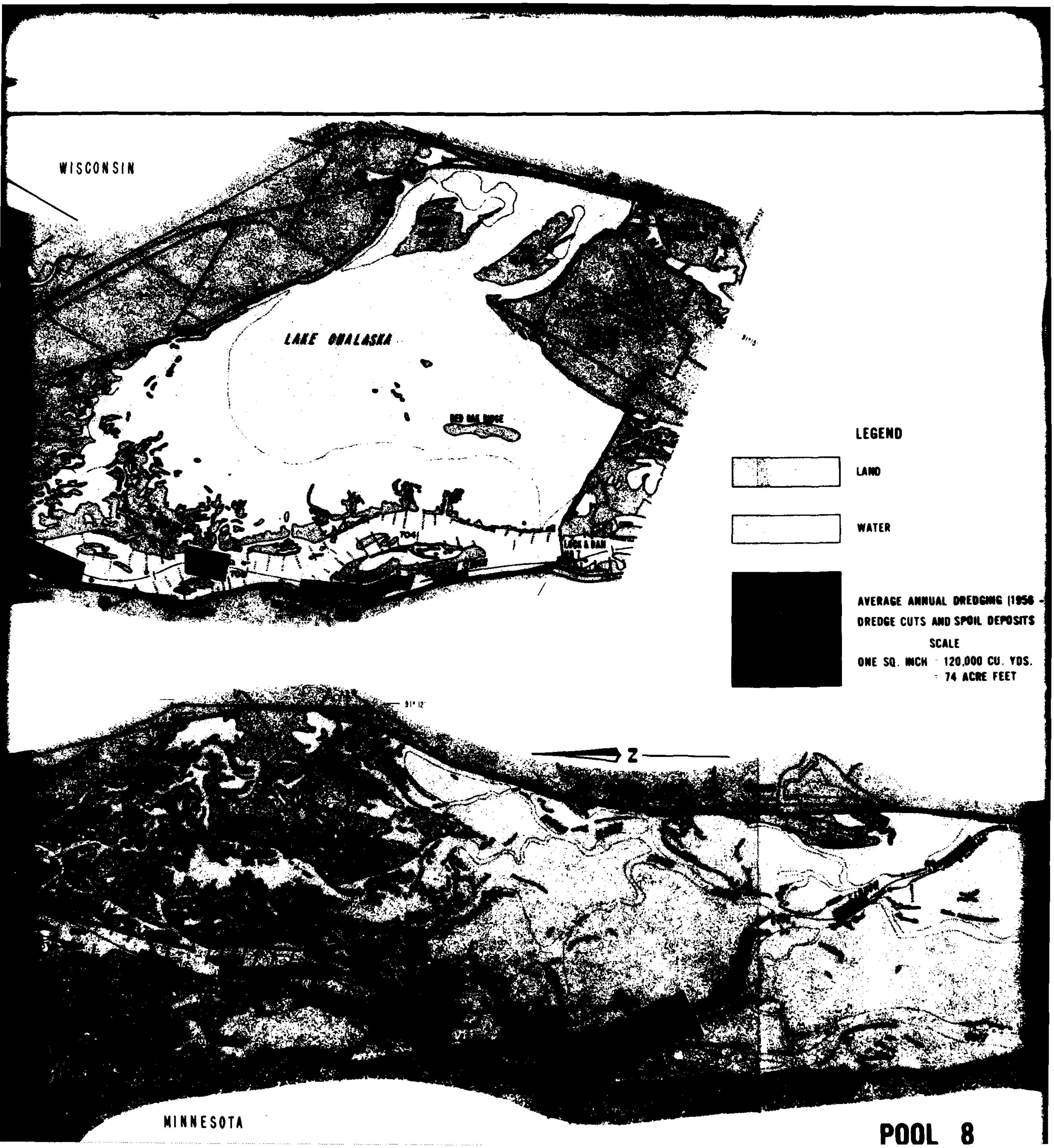
UPPER MISSISSIPPI RIVER BASIN

IOWA, MINNESOTA, SOUTH DAKOTA AND WISCONSIN

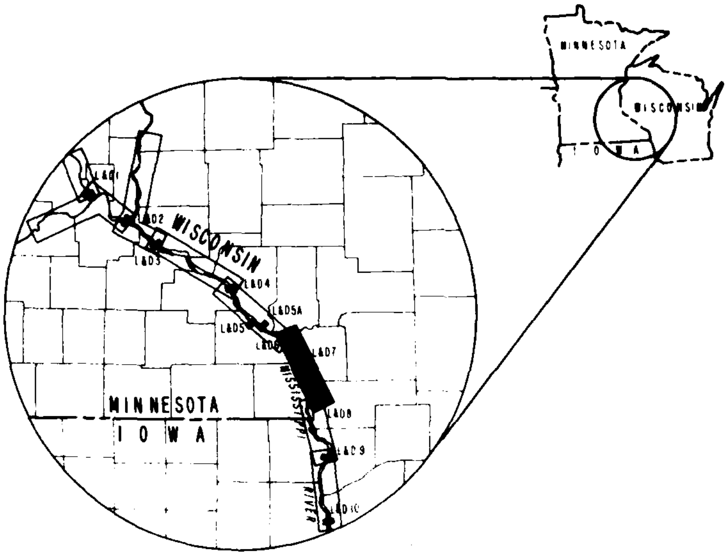
3

2-20-78
5,R-36,607


U S DEPARTMENT OF AGRICULTURE
POOL 7
87,000 Cubic Yards = 54 Acre Feet
WISCONSIN
LA CROSSE CO
TREMPEALEAU COUNTY
BLACK RIVER
TREMPEALEAU
LOCK & DAM NO. 6
WINONA CO
MINNESOTA
WINTERS LANDING
WISCONSIN
LA CROSSE CO
LA CROSSE
BLACK RIVER
BLUE LAKE
SOURCE
THEMATIC MAPS COMPILED BY SCS LINCOLN CARTO STAFF
AND FROM INFORMATION FURNISHED BY FIELD TECHNICIANS
BASE MAP CHARTS WERE PREPARED FROM LATEST SURVEYS
BY THE U.S. ARMY CORPS OF ENGINEERS OFFICES AND FROM
AERIAL PHOTOGRAPHY 1964


WISCONSIN
LAKE ONALASKA
LEGEND
LAND
WATER
AVERAGE ANNUAL DREDGING (1956 -
DREDGE CUTS AND SPOIL DEPOSITS
SCALE
ONE SQ. INCH = 120,000 CU. YDS.
= 74 ACRE FEET
91° 12'
N
MINNESOTA

POOL 8



LEGEND

LAND

WATER

AVERAGE ANNUAL DREDGING (1956 - 1974)
DREDGE CUTS AND SPOIL DEPOSITS

SCALE

ONE SQ. INCH = 120,000 CU. YDS.
= 74 ACRE FEET

AVERAGE ANNUAL DREDGING VOLUME AND LOCATION MAP

GREAT I

UPPER MISSISSIPPI RIVER BASIN

IOWA, MINNESOTA, SOUTH DAKOTA AND WISCONSIN

POOL 8

ubic Yards = 95 Acre Feet

3

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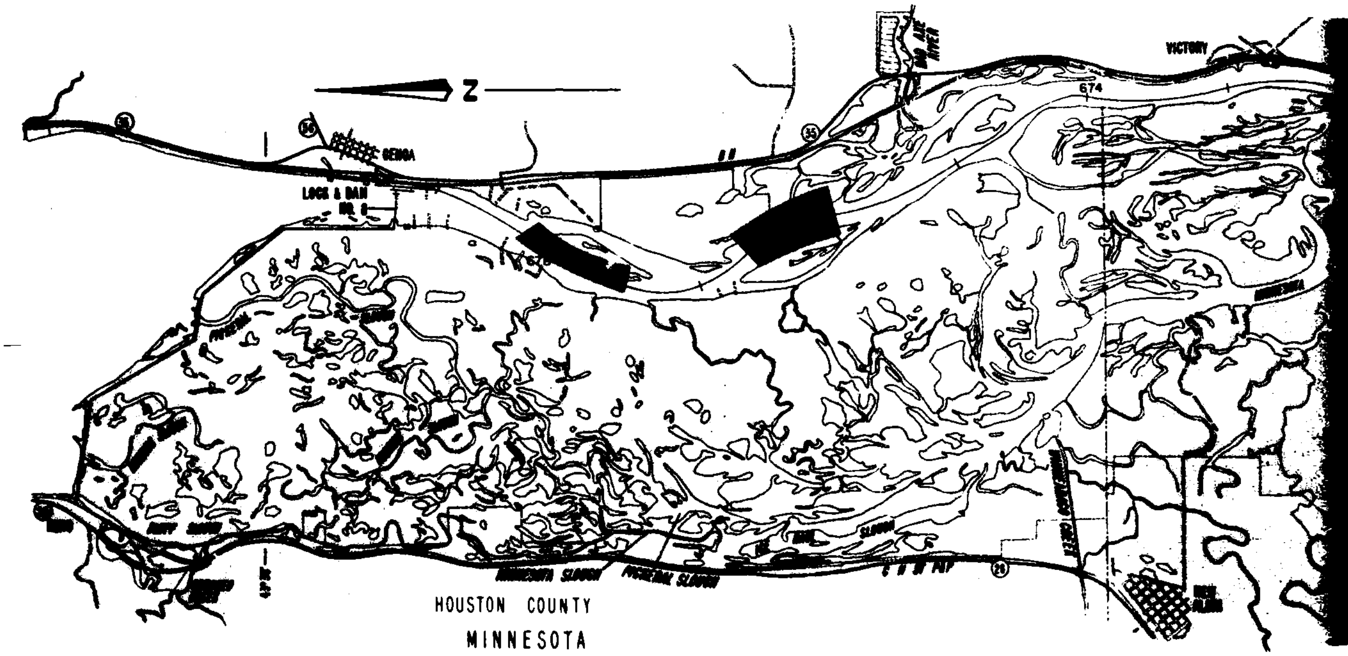
U. S. DEPARTMENT OF AGRICULTURE

POOL 9

121,000 Cubic Yards = 75 Acre Feet



LEGEND

LAND

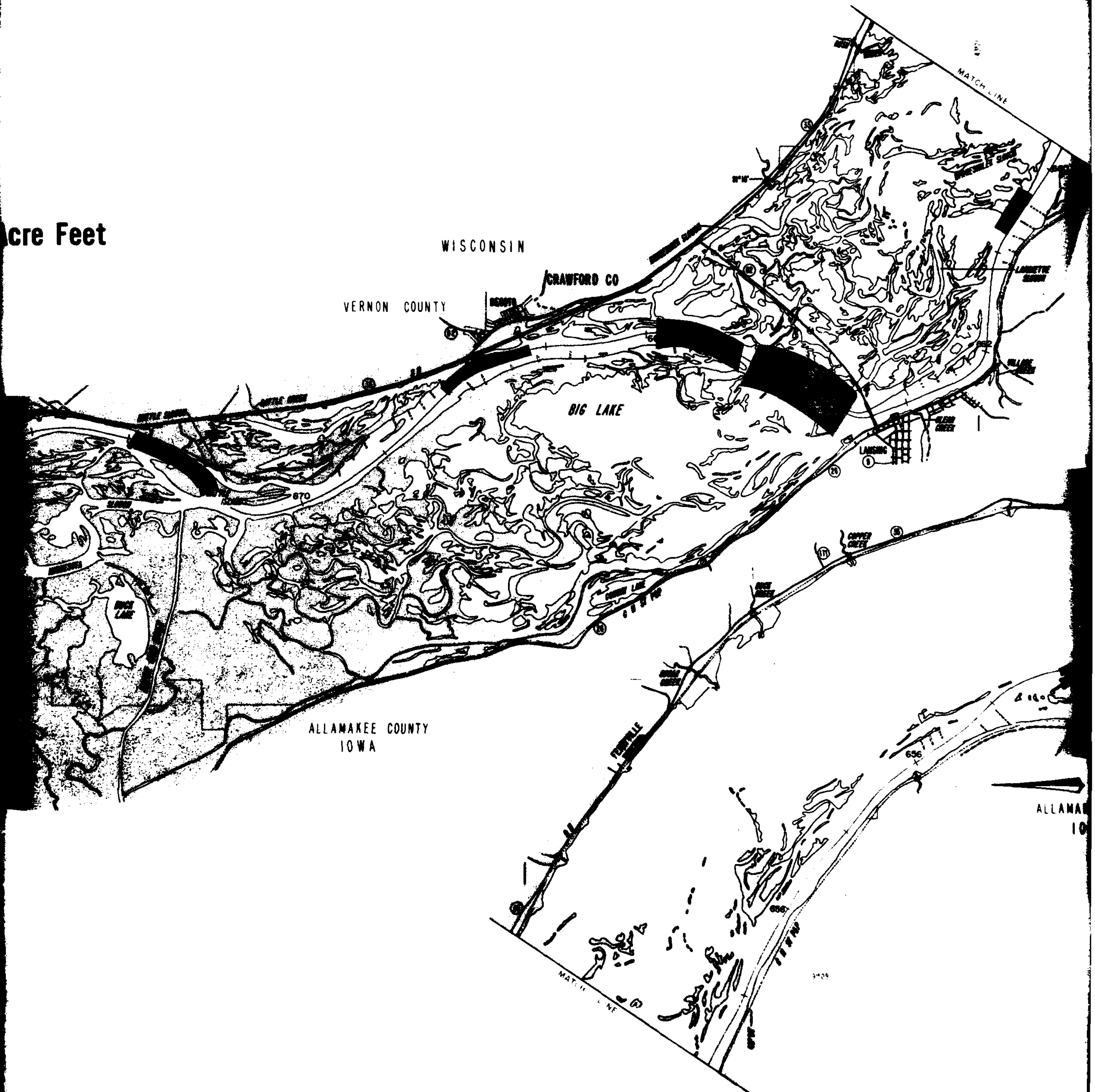
WATER

AVERAGE ANNUAL DREDGING (1956 1974)
DREDGE CUTS AND SPOIL DEPOSITS

SCALE
ONE SQ INCH 120,000 CU YDS 74 ACRE FEET

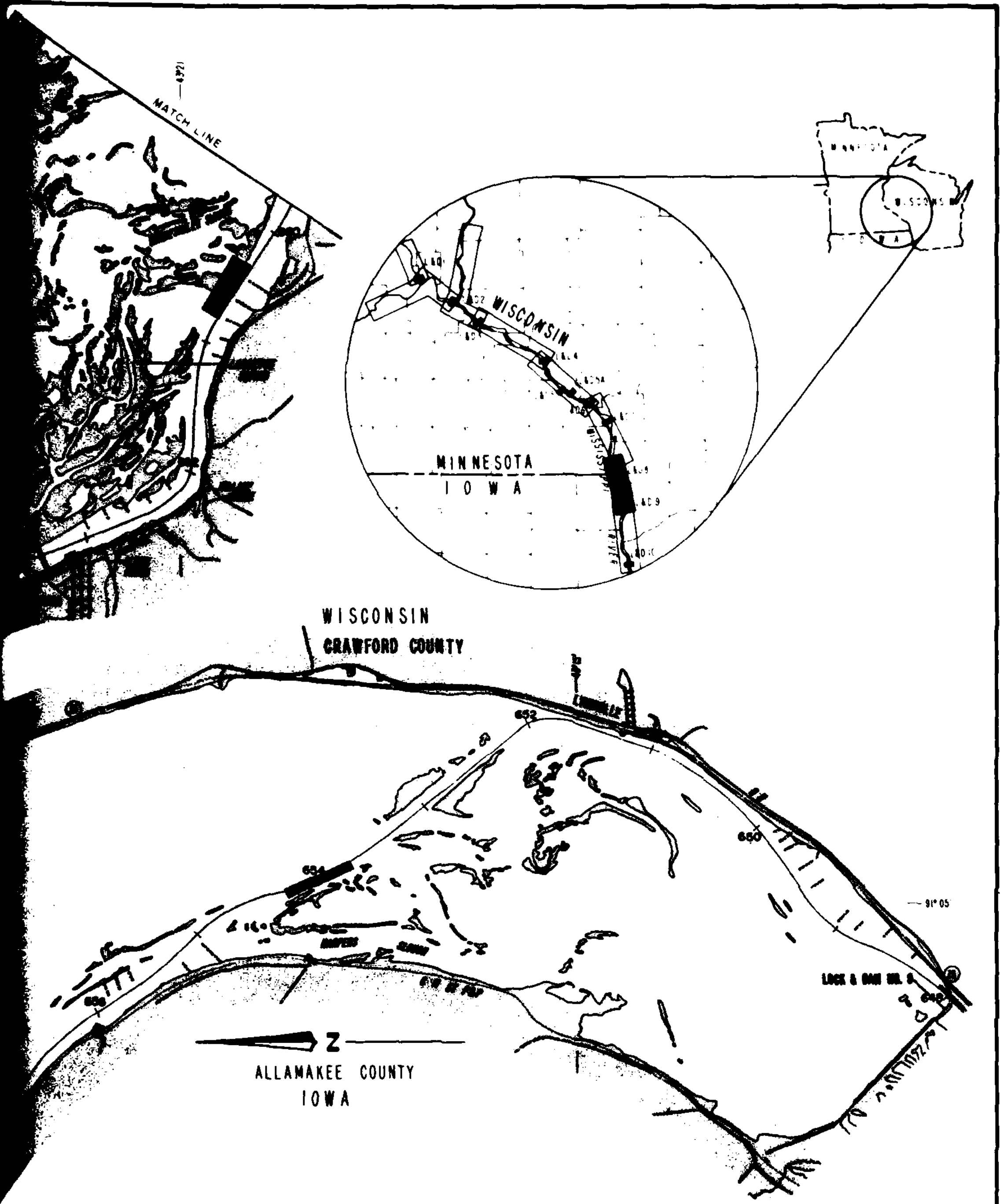
SOURCE
THEMATIC MAPS COMPILED BY [illegible]
AND FROM INFORMATION FURNISHED BY [illegible]
BASE MAP CHARTS WERE PREPARED FROM LATEST SURVEYS
BY THE U.S. ARMY CORPS OF ENGINEERS [illegible] AND FROM
AERIAL PHOTOGRAPHY [illegible]
[illegible]

Acre Feet



WISCONSIN
CRAWFORD CO
VERNON COUNTY
BIG LAKE
LANSING
670
656
MATCH LINE
MATCH LINE
ALLAMAKEE COUNTY
IOWA

2



AVERAGE ANNUAL DREDGING VOLUME AND LOCATION MAP

GREAT I

UPPER MISSISSIPPI RIVER BASIN

IOWA, MINNESOTA, SOUTH DAKOTA AND WISCONSIN

3

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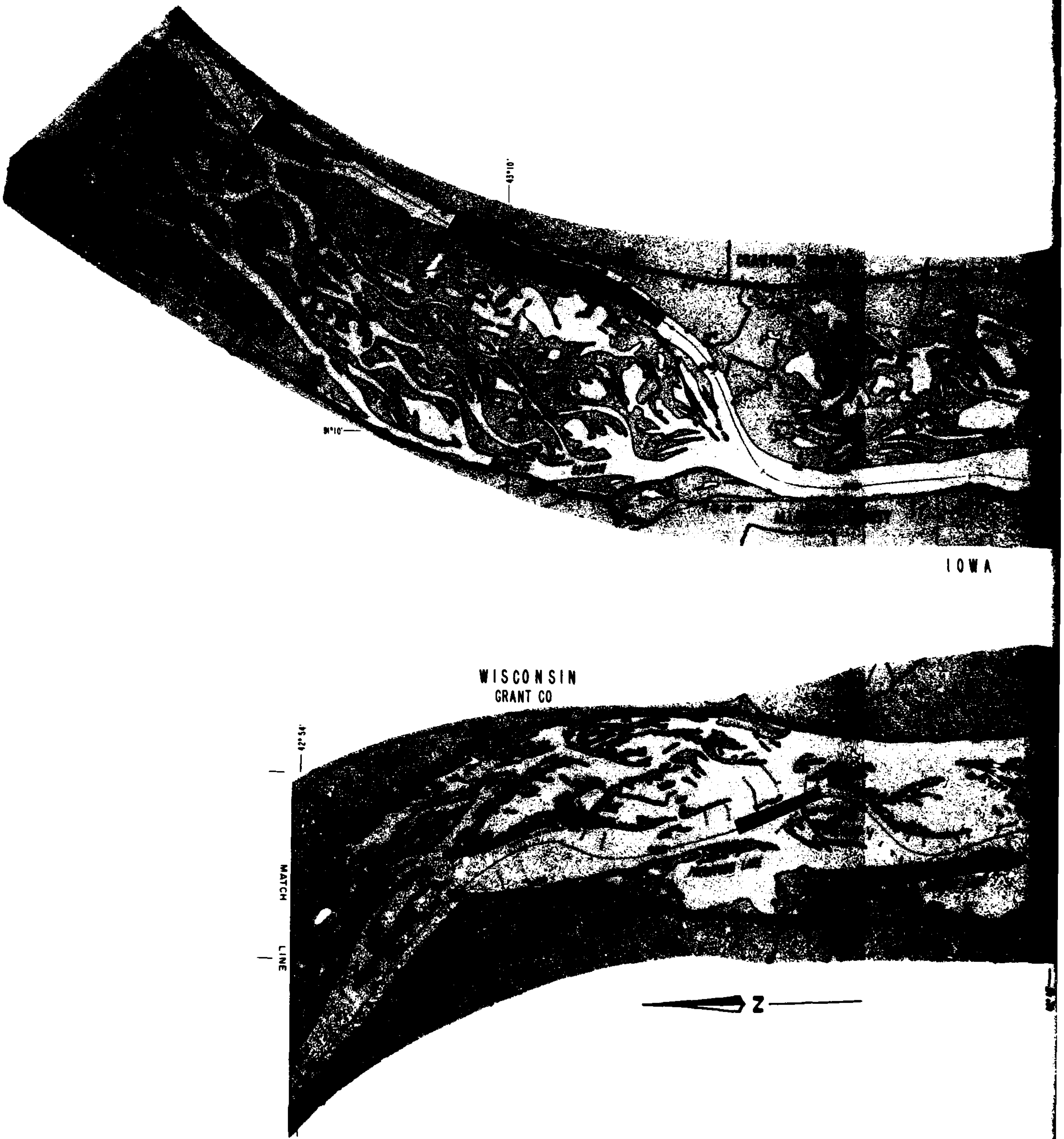
U. S. DEPARTMENT OF AGRICULTURE



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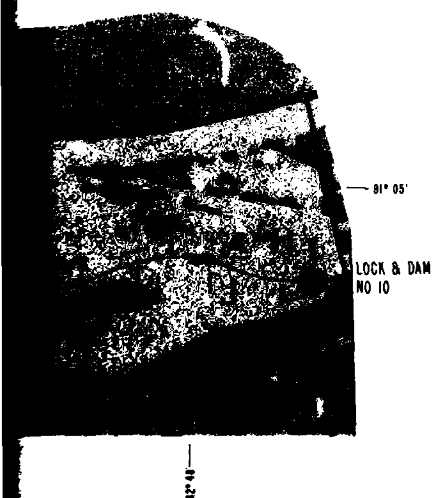
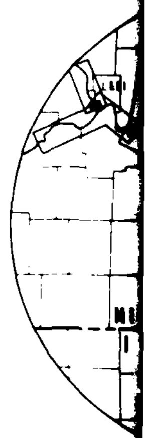
POOL 10

73,000 Cubic Yards = 45 Acre Feet





LEGEND

LAND

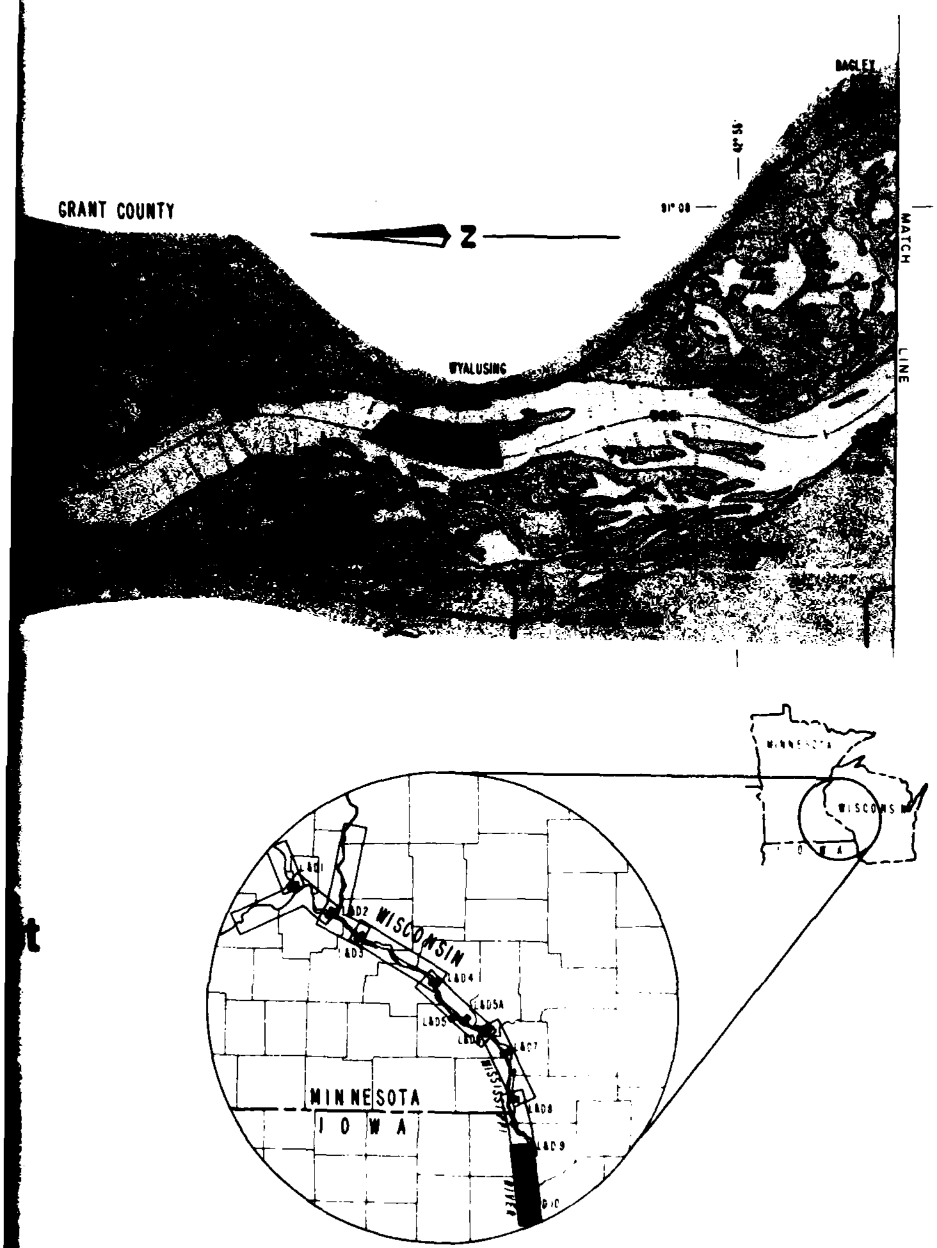
WATER

AVERAGE ANNUAL DREDGING (1956 - 1974)
DREDGE CUTS AND SPOIL DEPOSITS

SCALE
ONE SQ. INCH = 120,000 CU. YDS. 74 ACRE FEET

2

0 1 2 MILES
1/76,800
1" = 6,400'



AVERAGE ANNUAL DREDGING VOLUME AND LOCATION MAP

GREAT I

UPPER MISSISSIPPI RIVER BASIN

IOWA, MINNESOTA, SOUTH DAKOTA AND WISCONSIN

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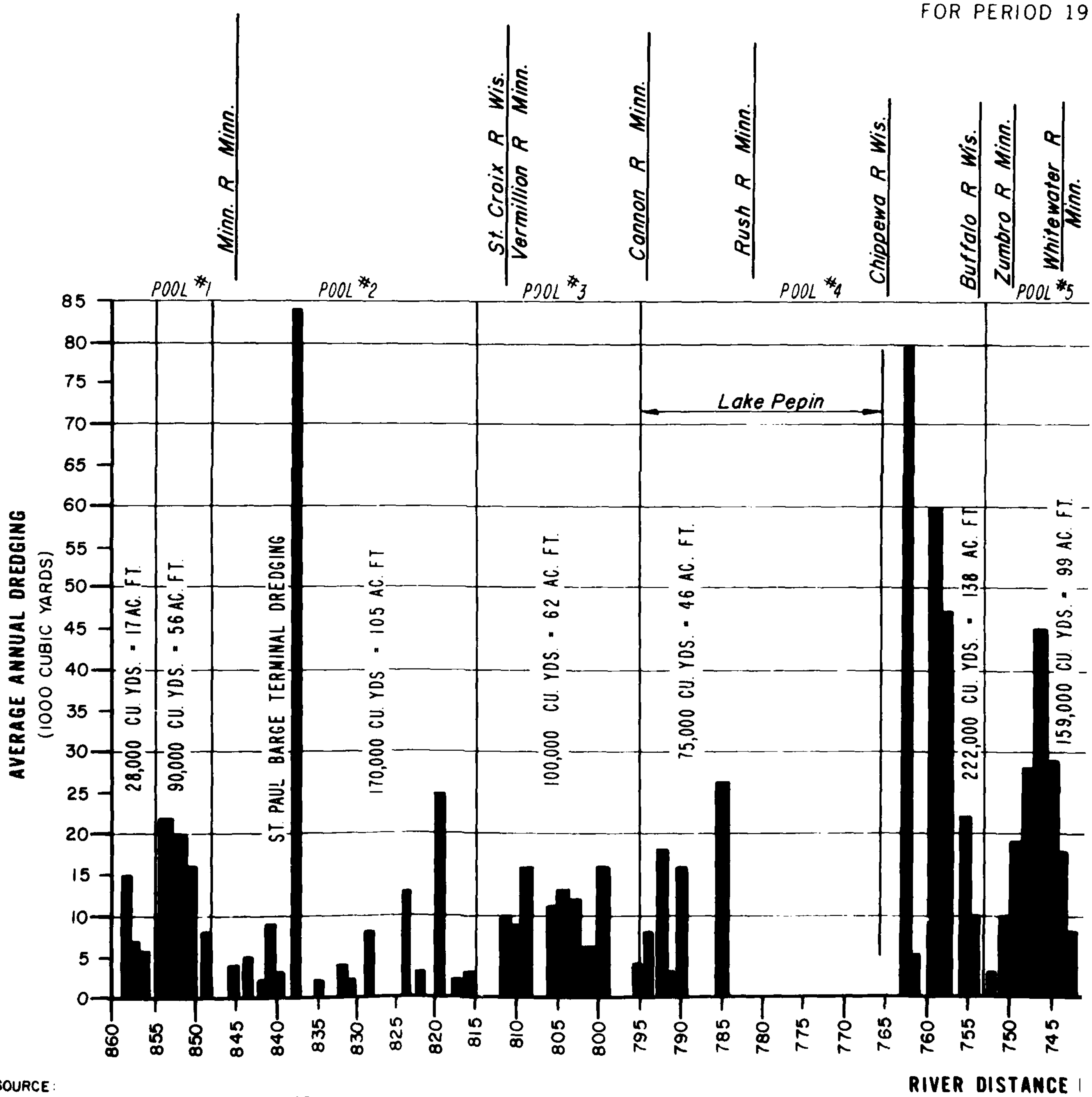
MISSISSIPPI RIVER - P

AVERAGE ANNUAL DRI

FOR PERIOD 19

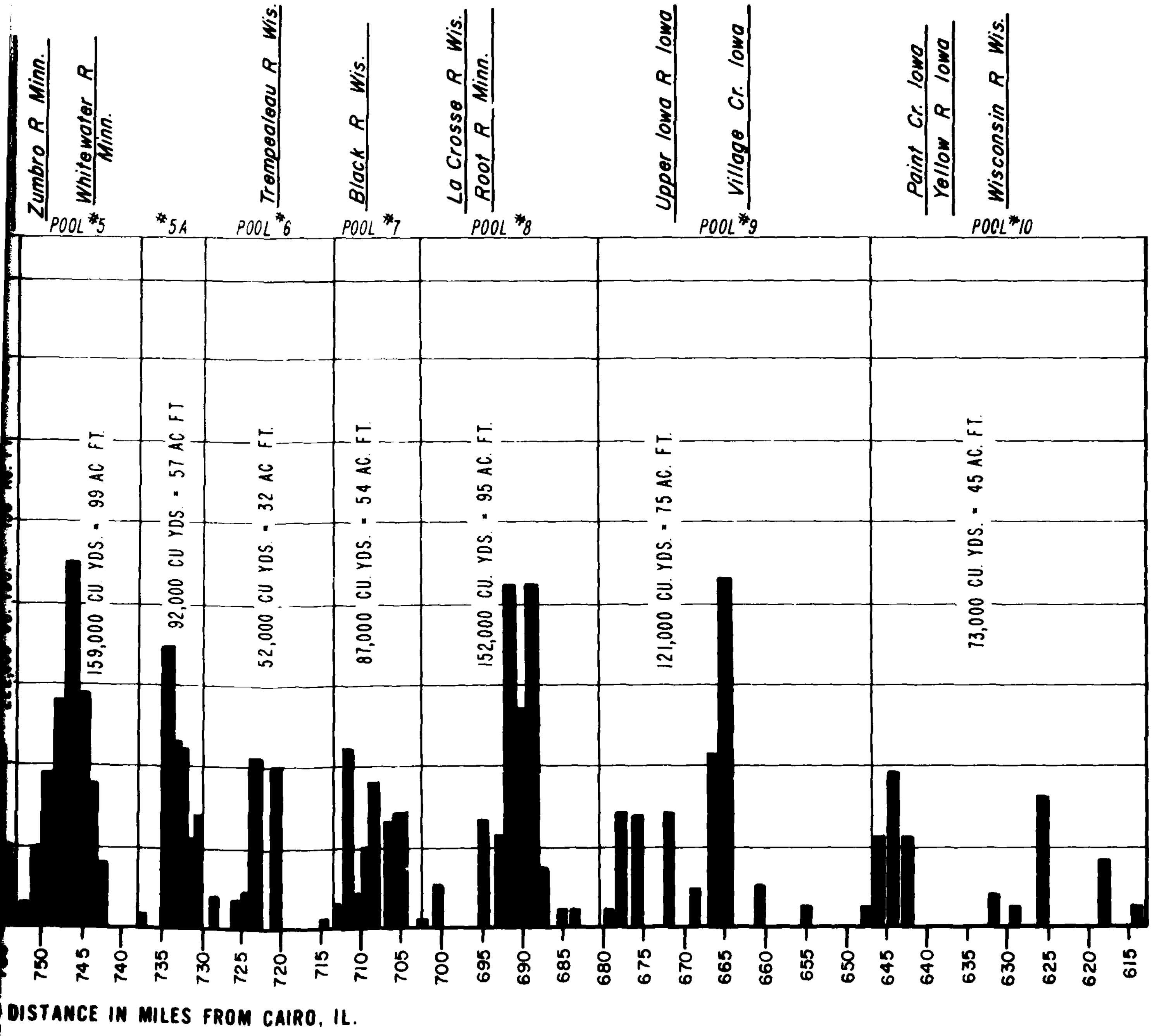


SOURCE:
CORPS OF ENGINEERS, ST. PAUL DISTRICT

]VER - POOL 1 THROUGH 10

NNUAL DREDGING VOLUME

PERIOD 1956 - 1974



2

1 provides the perspective of the system requirements. Channel maintenance has been accomplished by the Dredge WM. A. THOMPSON and Derrickbarge HAUSER. The THOMPSON is a 20-inch hydraulic dredge. The HAUSER is a 4-cubic yard clamshell dredge. The THOMPSON does the major volume of dredging in the St. Paul and Rock Island Districts.

Before 1974, dredging was normally programmed to a depth of 13 feet below low control pool (LCP); the two exceptions to this norm were the Minnesota River 9-foot channel project and the Mississippi River emergency dredging in 1965 and 1969. The original design on the Minnesota River limited dredging to 11 feet in consideration of riverbank stability. During 1965 and 1969, Mississippi River dredging depths were limited to 12 feet, and channel widths were restricted to allow timely completion of dredging to allow for navigation. Full channel widths with a 13-foot dredging depth were implemented the following years.

LCP or minimum water surface elevation is defined by the St. Paul District's hydraulic engineering staff. It is determined by considering the maximum allowable drawdown during higher discharges downstream of the primary control point and project pool elevation at zero flow upstream of the primary control point. A full, detailed description of the Upper Mississippi River project's pool operation is available for review in the environmental impact statement.(1)

---

(1) "Final Environmental Impact Statement, Operation and Maintenance, 9-Foot Navigation Channel, Upper Mississippi River, Head of Navigation to Guttenberg, Iowa," prepared by U.S. Army Corps of Engineers, St. Paul District, Volume 1, August 1974, pages 20-25.

The following are the channel widths maintained on tangent (straight) sections of the rivers:

River	Location	Width
Mississippi	Pools 3 through 10	300 feet
Mississippi	Locks and dam 2 to head of navigation (mile 857.6)	200 feet
St. Croix		300 feet
Black		300 feet
Minnesota		100 feet

Channel widths on bends were increased to as much as 550 feet. Widths were determined through experience considering bend radius, river currents and motor vessel operator comments.

To increase the channel width longevity, additional overwidth or advance dredging was accomplished as equipment and funding capability allowed. This practice was considered essential to insure adequate channel width during the absence of the Dredge THOMPSON; it provided capacity for future shoaling during high flow periods. Advance dredging is very efficient with a large hydraulic dredge which, once mobilized and set up at a dredging location, is able to dredge the additional volume required with a relatively small increase in dredging time.

Channel conditions were surveyed by one hydrographic survey crew; three additional crews assisted following the annual spring runoff. Sonar surveys were used to identify areas of shoaling, and manual detail surveys were

conducted for detail channel condition. Channel condition surveys were conducted after open river flow conditions passed and pools were reestablished. Channel maintenance dredging was scheduled when the channel depth shoaled to 11 feet or less below LCP.

A sediment trap experiment was conducted by dredging 313,800 cubic yards in the Chippewa River channel in May 1965. The trap was located 0.5 to 0.8 mile upstream of the confluence of the Mississippi and Chippewa Rivers. It was not pursued further because the trap filled in 1 year, and the benefit-cost ratio of dredging at the trap in lieu of the channel appeared insufficient. Further detail is available in the "Final Environmental Impact Statement, Operation and Maintenance, 9-Foot Navigation Channel, Upper Mississippi River, Head of Navigation to Guttenberg, Iowa," prepared by the U.S. Army Corps of Engineers, St. Paul District, August 1974.

From 1974 to 1978, the St. Paul District conducted an extensive pilot study program to evaluate the impact of modifying channel maintenance parameters. Details and results are presented in Sections IV through VI of this report.

III. RIVER PROCESSES

A. Introduction and Acknowledgment

An alluvial river is continually changing its position and shape as a consequence of hydraulic forces acting on its bed and banks. These changes may be slow or rapid and may result from natural environmental changes or changes caused by human activities. When a river channel is modified locally, the change frequently modifies channel characteristics upstream and downstream. When environmentalists, river engineers, and others involved in river development consider local modification of a river, they must remember that the river is dynamic, not static, and that possible long-term effects in and outside the local area should be analyzed.

B. Geomorphology of the Upper Mississippi River

Much of the material in this section and the following section, River Mechanics, is from the following sources prepared by Colorado State University under contract to the U.S. Fish and Wildlife Service (see Appendix D of this report for complete citations):

1. "A Geomorphic Study of Pool 4 and Tributaries of the Upper Mississippi River," by D. B. Simons et al., 1976.

2. "The River Environment," by D. B. Simons et al., 1975.

3. "A Summary of the River Environment," by D. B. Simons et al., 1976.

To predict long-term river responses to modifications, it is important to know the river's history and the factors that determine its present configuration. The present morphology of the river valley was essentially determined by glacial events in the Pleistocene period which ended about 10,000 years ago.

As the glaciers melted, the clear water discharge from the large glacial lakes resulted in a greater sediment transport in the Mississippi River, thus removing large quantities of bed material. This degradation lowered the riverbed gradient. After the retreat of the glaciers and subsequent reestablishment of drainage to the north, a much smaller river occupied the Mississippi Valley. With its capacity reduced, the Mississippi River could no longer remove all the sediment introduced by the tributaries and deposition occurred in the valley. Deposition is still occurring. Lane (see reference 5, Appendix D) predicts that the filling will continue until the slope is steeper - probably about as steep as the river was before the glacial period.

Postglacial growth occurs because tributary streams have higher gradients than the main stream and consequently transport a greater sediment load. Because the main stream cannot move the increased load as efficiently, bars and a delta often form at the mouth of major tributaries. The present Mississippi River adapts to its inability to move all the sediment from the tributaries by becoming shallower and wider near the tributaries, with

divided flow around numerous islands and bars. Because this condition is unsuitable for navigation on the river, man has controlled the river by artificially removing the sediments and training the river to stay in the main channel.

Lane concludes that filling of the valley will go on very slowly because it has to fill the entire width of the valley and the annual sediment discharge of the tributaries is small in comparison to the size of the valley. Most of the sediment deposition probably takes place in ponds, lakes, and secondary channels, where conditions are favorable for deposition, rather than in the main stream. In fact, the main channel may even enlarge, since the tendency is to fill the side channels forcing the entire flow into the main channel. When the aggradation has progressed to the stage where the river can carry the entire sediment load brought to it by its tributaries, the main channel will probably be largely free from islands, slough, lakes, ponds, and secondary channels. However, this process could take thousands of years.

The configuration of a river as viewed on a map or from the air can be classified as straight, meandering, braided, or some combination of these (Figure 1). The form of much of the Upper Mississippi River is "island braided". The river is not braided in the usual sense in that the islands are relatively stable and vegetated. Lane (1957) concludes that, generally, the two primary causes for a braided condition are probably: (1) overloading; that is, the stream may be supplied with more sediment than it can carry,

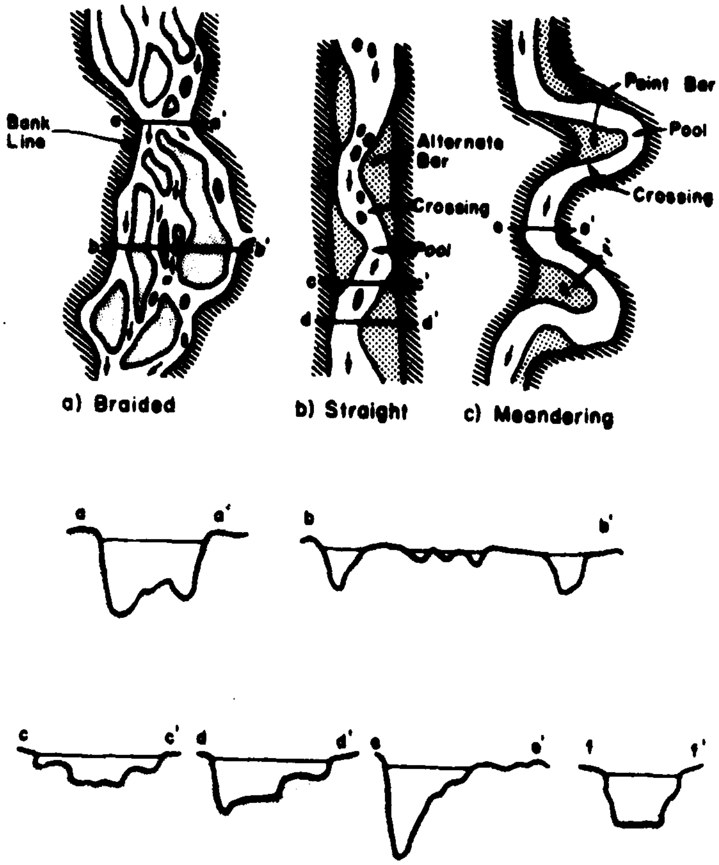


Figure 1 River Channel Patterns
(after Simons, Lagesse, Chen, and Schumm, 1975)

resulting in deposition of part of the load, and (2) steep slopes, which produce a wide, shallow channel where bars and islands form readily. The main channel of the Upper Mississippi River often has the characteristics of a meandering channel, with bars, pools, and crossings (Figure 2). Natural alluvial channels generally avoid a straight alignment. Even in straight channels, the thalweg oscillates transversely and has the appearance of a meandering channel. In a straight channel, the alternate bars and the thalweg are continually changing; straight channels should be avoided when attempting to stabilize a river.

Lane (1957) finds a relationship among slope, discharge, and channel pattern in meandering and braided streams (Figure 3). The Upper Mississippi River plots in the meander zone. Although the Upper Mississippi River has a definite meandering aspect, at least portions have a braided character. However, the Upper Mississippi River does not have the steep slopes generally associated with braiding. Lane (1957) recognizes the braided character of some reaches and notes that the conditions producing braiding are unusual. Braiding on the Upper Mississippi River is of the overloading type and is closely related to the unique glacial history of the basin.

An understanding of the crossing and pool sequency of meandering reaches is necessary to determine a dredging program. Rivers are deep along the concave banks of bends and shallow in the tangents between bends (Figure 1). Consequently, the thalweg profile exhibits a series of pools separated by shoals (crossings or bars).

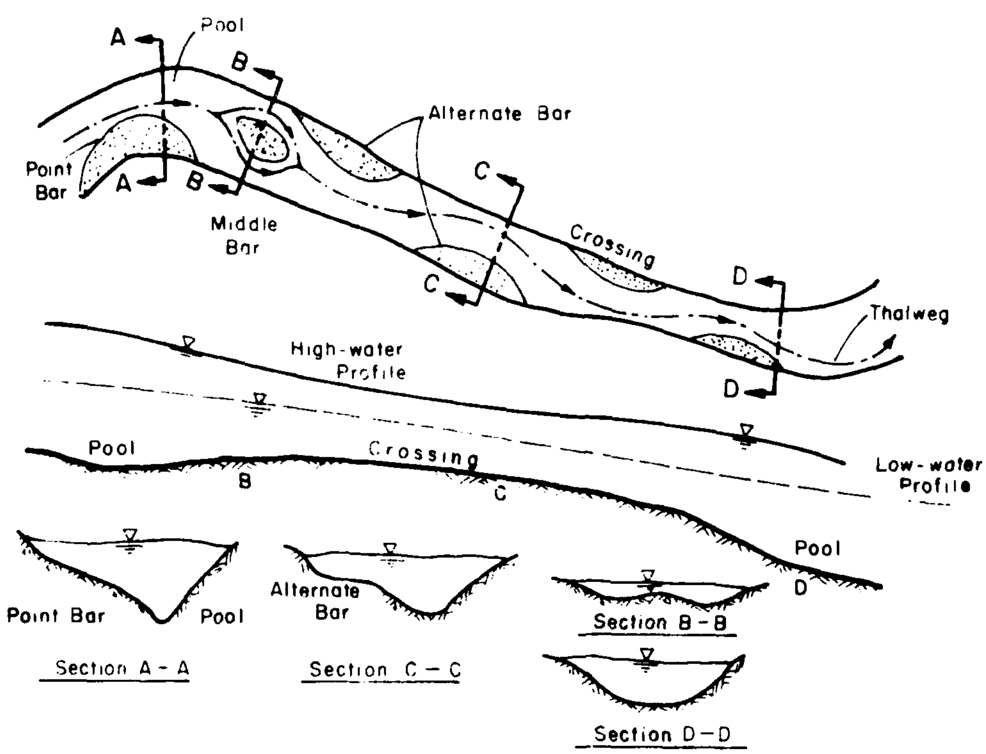
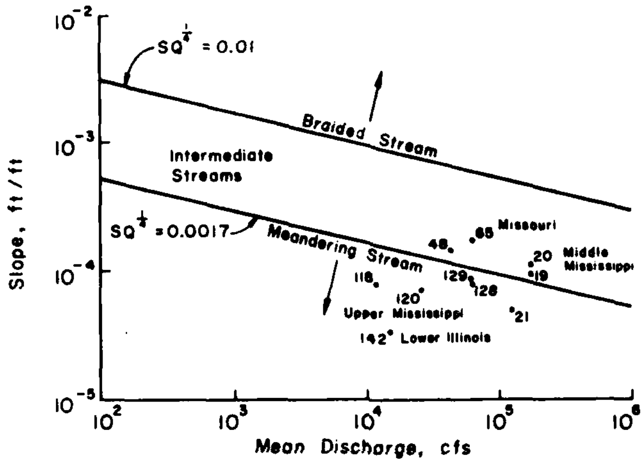


Figure 2 Plan View and Cross Section of a Meandering Stream.
(after Simons, Lagasse, Chen, and Schumm, 1975)



Identification of Reaches Plotted

19 Middle Mississippi – St. Louis to Chester
20 Middle Mississippi – Chester to Cape Giradeau
21 Ohio River
48 Lower Arkansas River
65 Missouri River
118 Upper Mississippi – St. Paul to Redwing
120 Upper Mississippi – LaCrosse to Lansing
128 Upper Mississippi – Hannibal to Louisiana
129 Upper Mississippi – Louisiana to Grafton
142 Lower Illinois River

Figure 3 Slope-Discharge Relation for Braiding or Meandering in Sand Bed Streams (after Lane, 1957)

Cross sections in bends are triangular (Figure 4), with the deepest points on the outer bank and shallow point bars on the inner bank. In the transition zone between bends, flow lines straighten, and the cross section takes the form of a wide, shallow trough forming a saddle or bar which the thalweg must cross in moving from pool to pool. The crossing controls the least available depth through the reach for navigation at a given stage, and it is on the crossings that dredging to obtain navigable depths is usually concentrated. During flood flows, the bends are generally scoured while there is deposition at the crossings; at low flows, conditions are reversed. The crossings tend to scour, and deposition occurs in the pools. As shown in Figure 4, the thalweg location also changes from high flows to low flows. The higher velocities and greater momentum of the high flows tend to follow a straighter path than low flows. The high stage thalweg skirts the inner bank and cuts across the tip of the point bar, in some cases opening a chute channel across the bar.

In summary, the characteristics of the Upper Mississippi River show the influence of Pleistocene glaciation and its aftermath. The river is truly alluvial in character; that is, it flows essentially in cohesive and noncohesive materials that have been or can be transported by the stream. Much of the river has an "island braided" pattern, often with a meandering main channel. The Upper Mississippi River is aggrading, so slowly that it can be considered essentially a graded stream - one where dynamic equilibrium exists between incoming sediment load and transport capacity.

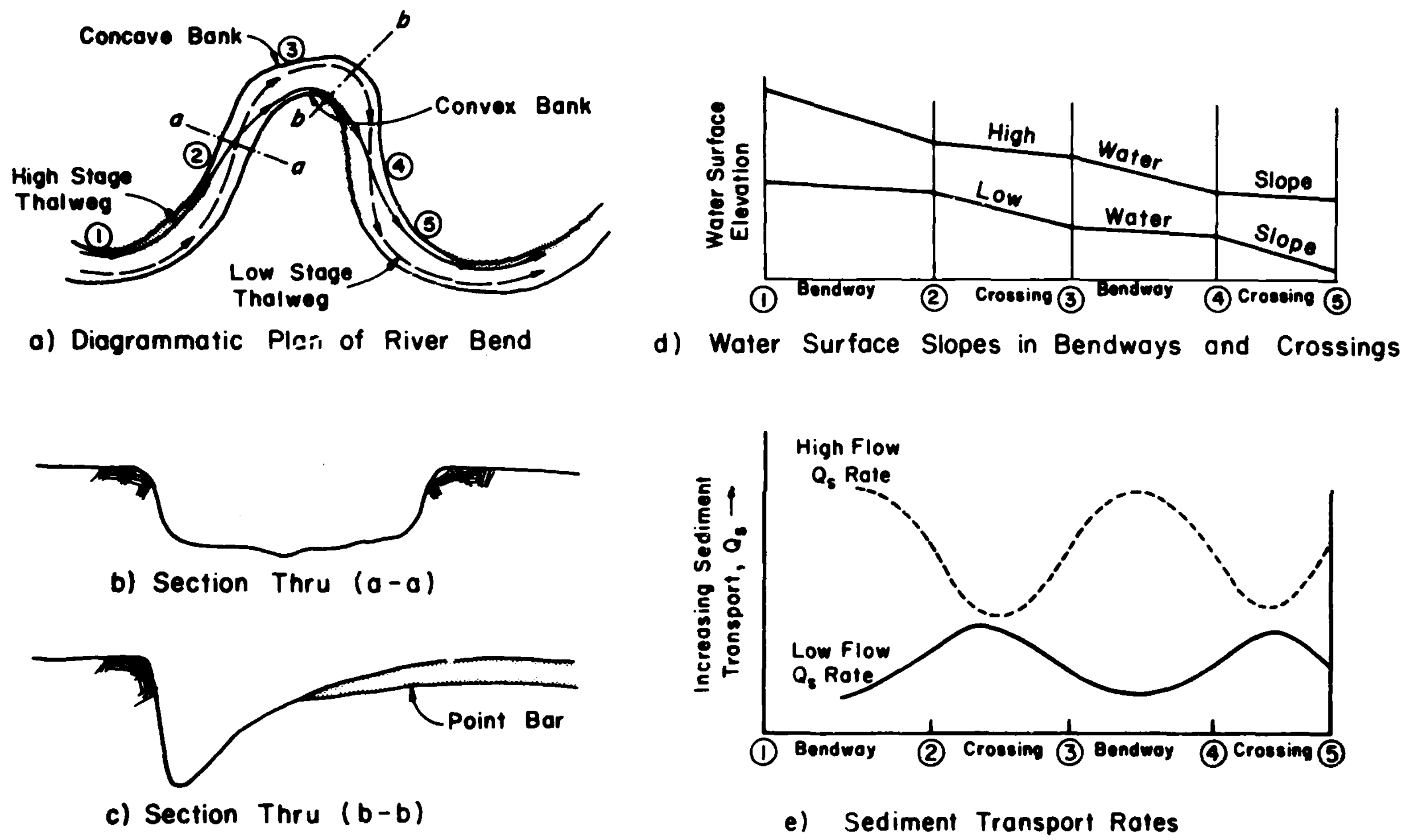


Figure 4 Characteristics of a River Bendway
(after Simons, Lagasse, Chen, and Schumm, 1975)

Although morphologic change within the channel is the norm, in terms of position within the floodplain, the Upper Mississippi River is relatively stable. This is particularly true in comparison to the Lower Mississippi River where large scale lateral shifting of the river's position, downstream migration of the meander pattern, and numerous natural cutoffs of meander loops have occurred. The relative stability of the upper river permits vegetation growth to the waterline.

C. River Mechanics

The movement of water and sediment in a river is governed by two laws of physics: conservation of mass and conservation of momentum. The conservation of mass law can be broken down into the sediment and water continuity equations. The sediment continuity equation states that the amount of sediment entering a reach of river minus the amount of sediment leaving the river must equal the change in the volume of sediment stored in the reach. The continuity equation for water is similar. From Newton's second law of motion, the change in momentum of a body per unit time equals the resultant of all external forces acting on the body. The momentum equation states that the change in momentum of the flow between the upstream and downstream ends of a reach equals the added momentum of lateral inflow minus forces acting on the flow. These forces include shear at the bed, slowing the flow and gravity propelling the flow. The two continuity equations and the momentum equation are usually expressed as partial differential equations and can be found in many hydraulic reference books.

AD-A126 968 GREAT I: A STUDY OF THE UPPER MISSISSIPPI RIVER VOLUME 2 FLOODPLAIN MANAG..(U) GREAT RIVER ENVIRONMENTAL ACTION TEAM SEP 80

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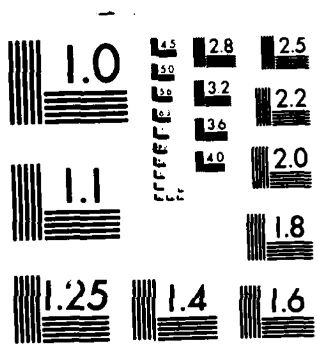

MICROCOPY RESOLUTION TEST CHART
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The three partial differential equations in their complete form have not been solved analytically, except for very simplified cases, thus the need for approximate numerical solutions through the use of the computer. Depending on the flow conditions, the equations can be simplified significantly.

Open channel flow can be some combination of uniform or nonuniform flow, steady or unsteady flow, and tranquil or rapid flow, although some combinations would be difficult to define. In uniform flow, the depth and discharge remain constant with respect to distance down the river. Also the velocity at a given depth is the same everywhere along the channel. In steady flow, no change in discharge occurs with respect to time. Tranquil or subcritical flow is distinguished from rapid or supercritical flow by a dimensionless number called the Froude number (F_r), which is defined by the ratio of inertia forces to gravitational forces in the system or may be defined by the ratio of the flow velocity of a small surface gravity wave in the flow. If F_r is less than 1, the flow is tranquil and surface disturbances propagate upstream as well as downstream. If F_r is greater than 1, the flow is rapid, and surface disturbances can propagate only in the downstream direction. If $F_r = 1.0$, the flow is critical and upstream-oriented surface disturbances remain nearly stationary in the flow. In most cases, the flow in the Upper Mississippi River is nonuniform and tranquil. The river flow may be considered steady within a short period but unsteady within a long period of time.

For steady flow, the momentum or energy equation is rearranged in the following form to compute the water surface profile:

$$L = \frac{H_2 - H_1}{S_0 - S_f}$$

where L is the distance between Sections 1 and 2, H is the total energy of the flow above the bottom, S_0 is the bed slope and S_f is the friction slope or energy slope. The specific head is defined by

$$H = \frac{V^2}{2g} + y$$

where V is the average velocity, g is the acceleration of gravity, and y is the flow depth.

The friction slope is the slope of the energy line representing the elevation of the total energy of flow. The slope is related to the velocity and depth by the following empirical relations:

1. Manning equation:

$$V = \frac{1.486}{n} R^{2/3} S_f^{1/2}$$

2. Chezy equation:

$$V = C R^{1/2} S_f^{1/2}$$

where R is the hydraulic radius which is equal to the cross-sectional area divided by the wetted perimeter. The Manning's roughness coefficient n

and the Chezy's discharge coefficient C are empirical coefficients representing channel roughness. These coefficients have been determined for a variety of channel types and can be estimated for other channels, based on knowledge of the general nature of the channel boundaries.

If the flow is uniform or nearly uniform, the friction slope can be assumed to be equal to the mean riverbed slope. This value can be used in Manning's or Chezy's equation to estimate the flow velocity and depth for a given discharge. The flow depth thus computed is known as the *normal* depth.

If the flow is nonuniform because of changes in slope of the bed, changes in the cross section (such as those caused by construction of dikes), obstructions in flow (such as locks and dams), or imbalances between gravitational forces accelerating the flow and shear forces retarding the flow, the flow depth will be different from the normal depth.

In alluvial channels such as the Upper Mississippi River, the roughness coefficient in the Manning's or Chezy's equation will vary with the bed form. The bed forms that may occur in a sandbed alluvial channel are plane bed without sediment movement, ripples, ripples on dunes, dunes, plane bed with sediment movement, antidunes, and chutes and pools. Typical bed forms are shown in Figure 5. Bed configurations are listed as they occur sequentially with increasing values of stream power.

Using differences in these bed forms as a basic criterion, flow in alluvial channels is divided into two regimes of flow separated by a transition zone. These two regimes of flow and their associated bed forms

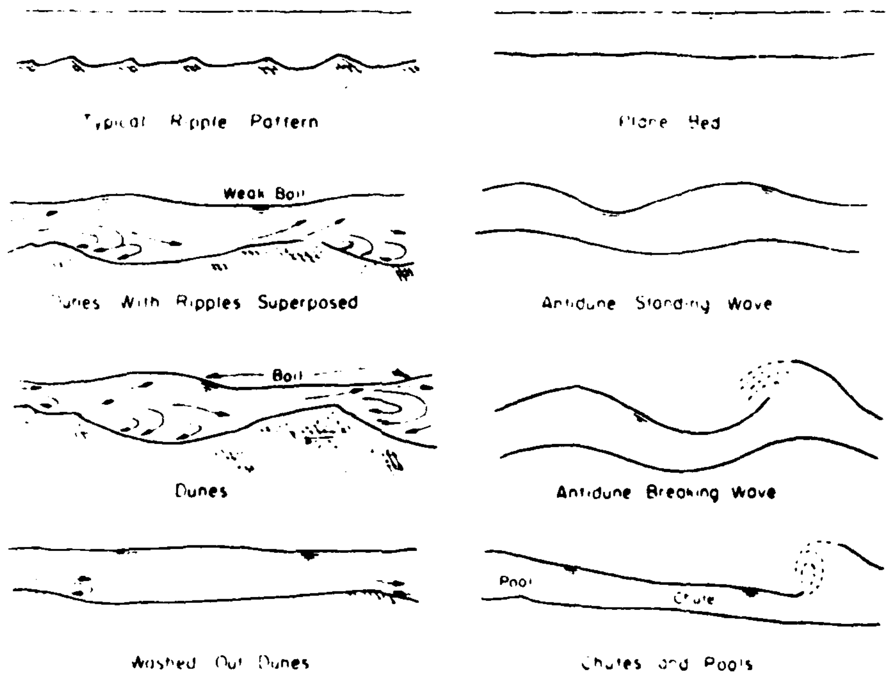

Figure 5 Forms of Bed Roughness in Sand Channels (after Simons, Lagasse, Chen, and Schumm, 1975)

are (1) lower flow regime (plane bed without sediment transport, ripples, ripples superposed on dunes, and dunes) and (2) upper flow regime (plane bed with sediment movement, antidunes, and chutes ar' pools). In the lower flow regime, resistance to flow is high, velocity is small, a: d sediment transport is small. In the upper flow regime, resistance to flow is low, velocity is large, and sediment transport is large. The Upper Mississippi River will generally be in the lower flow regime. As the bed configurations change, resistance changes, Manning's "n" varies from a typical value of 0.014 for plane bed without se'iment motion to values as high as 0.040 for a dune bed. Typically, Manning's "n" values for the Upper Mississippi River range from 0.020 to 0.035.

For sediment to reach a given point, two conditions must be satisfied: (1) it must have been eroded somewhere in the river basin above the cross section, and (2) it must be transported by the flow from the place of erosion to the cross section. Each of these conditions may limit the sediment rate. Usually, the finer part of the load is limited by its availability in the watershed; the flow can easily carry large quantities of this finer load. This part of the load is designated as wash load and has little effect on dredging. The coarser part of the load is limited by the transporting power of the stream. This part of the load is designated the bed-material load. A rule of thumb assumes that the bed-material load consists of sizes equal to or greater than 0.062 mm (millimeter), about the division between sand and silt. The characteristics of the material in the bed of the stream are closely related to those of the bed-material load. Sediment particles can be

transported by rolling or sliding along the bed (bed load) and/or as suspended material supported by the flow (suspended load). The reader should refer to the glossary for definitions of the various types of sediment load.

As the discharge in a river increases, its power to move bed material also increases. This will cause the smaller particles on the bed to be transported first, resulting in a layer of larger particles being left on the bed which cannot be moved by the flow. This is called an armor layer. For this layer to form, the bed must contain a variation in particle size. Armor layers do form in the Upper Mississippi River, but because of the fairly uniform sand bed material these layers are usually not large enough to withstand flood flows. However, they can be important to the dredging program. Armor layers that form in the spring at river crossings can prevent normal low flow erosion of the crossings. Postflood, reduced-depth dredging of the crossing can remove the armor layer and allow the crossing to be further deepened by the flow.

The determination of the total quantity of sediment transported through a reach is mainly based on field measurement supplemented by theoretical methods developed to compute the sediment load that cannot be measured. Most sediment samplers cannot measure very close to the bed - this is called the unmeasured zone. The theoretical Modified Einstein Method is usually used to estimate the sediment load in the unmeasured zone. An alternate field measurement method to find the total sediment

load is to use a bed load sampler such as the Helley-Smith; however, bed load sampler results are not accepted by all hydraulic engineers. The USGS (U.S. Geological Survey) in Wisconsin uses the Helley-Smith sampler to find total sediment load,; and the USGS in Minnesota does not. Published sediment data by the USGS usually is for suspended sediment; bed load measurements are sparse. Unfortunately, it is the bed load that affects the navigation channel.

Sediment discharge can also be determined by theoretical and empirical sediment transport functions that relate the sediment discharge to the river hydraulics. Commonly used methods are those of Einstein, Yang, Toffaleti, Colby, and Meyer-Peter, Mueller. For descriptions of these methods, the reader is referred to Simons and Senturk, "Sediment Transport Technology," 1977. To calibrate and verify these methods, at least limited field measurements of sediment load should be made. Most of the methods are for bed-material discharge, and none have given consistently reliable results. Toffaleti's and Yang's methods have been used by Colorado State Univeristy for its model studies in pool 4 and the Chippewa River.

Often it is not possible to predict the response of a river to a proposed action without the use of a model. For an alluvial river, this will probably be a mobile-bed physical model or a mathematical model.

Ideally, a physical model would be an exact copy of the prototype, only scaled down to a manageable and affordable size. Unfortunately, the forces acting on the prototype do not scale down at the same rate as the geometry. Also, it is often not practical to use the same scale in the

vertical and horizontal directions of the model. The bed material size is usually not scaled down at the same ratio as the vertical or horizontal scale because of the very small sizes that would result for the model. To insure that the model accurately represents the prototype, it is necessary to verify the model. The model verification consists of the reproduction of observed prototype behavior by the model. For example, a model may be verified for observed bed-level changes over a certain reach of the river. The predictive use of the model should be restricted to the aspects for which the model has been verified. Use of the model is based on the premise that, if the model has successfully reproduced the phenomenon of interest as observed on the prototype, it will reproduce the future response of the river over a similar range of conditions.

Disadvantages of physical models are that they are usually quite expensive to construct and are limited to the specific reach of river they model. On the other hand, a generalized computer model can often be used for any reach of river at a smaller cost. The computer model for an alluvial river solves the basic governing equations in numerical form. These equations include basic flow equations, the differential equations of nonuniform and unsteady flow, the sediment transport, and criteria to predict the bed deformations. Depending on the results needed and the nature of the flow in the prototype, it may be possible to eliminate or simplify some of the equations. Because of the complexity of the equations and their interaction, most computer models are for one- or two-dimensional flow fields only. This is usually satisfactory because three-dimensional

processes become important only when looking into the details. As with a physical model, it is necessary to calibrate and verify math models. To perform a satisfactory calibration sufficient data must be available. These data should include:

a. Geometric data of the modeled river reach.

b. Hydrographs of stage, flow, and sediment discharge.

c. Geological and physical properties of the bed and bed materials.

IV. PARAMETER IDENTIFICATION AND INVESTIGATION METHODOLOGY

A. Parameters

The work group identified the following parameters which affect dredging requirements:

1. Hydrology and sediment transport capability - Mississippi River and tributary discharge.
2. Dredging depth.
3. Navigation channel width.
4. Channel alignment.
5. Channel longevity (dredging frequency).
6. Tributary sediment supply.
7. Wing dam and closing dam design.
8. Dredged material placement (secondary erosion and in-channel placement).
9. Channel condition/initiation of maintenance.
10. Pool level.
11. Impacts of navigation.
12. Location of navigational aids (buoys, etc.).

B. Investigation

1. The work group recognized the complex interrelationship among these parameters and the scope of work involved with 284 miles of channel with 122 separate historic channel maintenance sites. The work group sought the best technical assistance available including capability beyond the team members. Dr. Al Anderson, University of Minnesota, and Dr. Daryl Simons, Colorado State University, were invited to review and discuss the effort required. Dr. Anderson is a leader in the physical modeling field. Dr. Simons has a world reputation in sediment transport mechanics and is a leader in the development of mathematical modeling.

2. Three basic methods of attacking the investigation were identified with the noted individual limitations:

a. Field Testing. The advantage of documented field tests is that they have the best reliability; the disadvantages are that the test conditions are limited by the hydrologic cycle experienced, variables cannot be tested under identical recurring conditions, the study period is short, and any failures pose a risk to continuing commerce.

b. Physical Modeling. This method has proven reliable in predicting the effects of parameter modification. It has an advantage over field tests because tests can be repeated with all parameters constant except the one

being tested. The primary disadvantages are cost, areal scope, and time requirements. Physical modeling of one dredge site would cost approximately $100,000. Only small sections of the river can be modeled without the scale affecting the correlation with actual field conditions.

c. Mathematical Modeling. A mathematical model is a computerized program of hydraulic and sediment transport equations which attempt to describe the river flow including water and sediment and its interaction with the riverbed. This method is relatively new and untested; only recent development of computer capability allowed initiation of a mathematical solution. A math model has a great advantage over a physical model because the model does not have to be built after each test. It is more time and cost effective than field testing or physical modeling but lacks full development and reliability. One- and two-dimensional sediment transport math models were considered.

(1) One-Dimensional Sediment Transport Math Modeling. Computerized programs are available from the Corps of Engineers, Colorado State University, and other sources to reasonably analyze general sediment transport in river systems. Colorado State University was under contract to conduct a limited scope one-dimensional analysis of lower pool 4 for the U.S. Fish and Wildlife Service. Using existing field data to calibrate a one-dimensional model, one can evaluate general trends. A true one-dimensional model is quite limited because any variation across the channel cannot be evaluated. In practical terms, the model can be used to compute

the average channel bottom depth with sufficient base data, but it cannot compute the depth at the outside of a river bend compared to depth at the inside of a river bend. The primary advantage it provides is continuity through a river system; it is capable of providing the response of the river upstream and downstream from the proposed modification. As an example, one can attempt to project the general impact of a sediment trap on the Chippewa River bed profile upstream of the trap and the impact on Mississippi River bed profile at Reads Landing, Minnesota, without testing it in the field or physically modeling the entire reach.

(2) Two-Dimensional Sediment Transport Mathematical Modeling. Although a two-dimensional model is similar to the one-dimensional math model in that equations are used to describe the river flow and interaction with the river bed, it attempts to describe the water and sediment flow across the channel as well. Three-dimensional flow phenomena such as secondary currents and velocity variations in the vertical dimension are not included. A two-dimensional model could theoretically describe the detail sediment profile change with time and flow across a river bend, the impact of varying dredging cut depth and/or width on the longevity of the channel under varying flow conditions, or the river response to a modified wing dam alignment. However, a two-dimensional math model has never been developed or tested for use on a river. The only known two-dimensional model being built at this time was being developed to study estuaries. Dr. Simons was doing basic research in this area and was very interested in developing a two-dimensional model for the Mississippi River and in applying it to our problem. Because of computer time and cost limitations, the anticipated

computer capability would not realistically allow application over the entire system but only at localized problem areas. The one-dimensional model can maintain continuity of water and sediment transport through the system to allow selective application of the two-dimensional system.

C. Approach

After a lengthy deliberation in which each representative on the work group had an opportunity to discuss a plan with his agency's staff, the work group decided to pursue the following investigation:

1. Field Tests. As many field tests of reduced depth and width dredging as feasible to determine the impact on dredging quantity, channel longevity, and navigation would be conducted. The extent of field testing would be limited by the Corps of Engineers capability to insure navigation in case of failure and survey capability to monitor and document the results. It was also recognized that the short time frame would limit long-term conclusions, but field tests would be required for any recommendations before total implementation could be considered.

2. Physical Modeling. Limited physical modeling would be required to improve the theoretical equations required in a two-dimensional model, including definition of the flow patterns at the wing dam - channel boundary area. A physical model at one site could thoroughly investigate the hydrology, depth of dredging, width of dredging, channel alignment, wing dam and closing dam effectiveness, and sediment trap

potential. This would allow specific recommendations of dredging depth, wing dam modifications required, and sediment trap efficiency and a better understanding of the relationship of the parameters affecting dredging. A film of the physical model process would be valuable for informing concerned private citizens and public officials of the problems encountered which might require further support and funding. The field tests and data collected could be used to calibrate the physical model. The field data and physical model results could be used to check the reliability of any math modeling and determine adjustments to the math model which might be anticipated. Physical modeling would cost over $100,000, but would definitely provide the best feasible solution to at least one site if all else failed and provide direction for further research and development required.

3. Math Modeling. Because math modeling was the only potential method available within a reasonable cost and time frame to analyze large reaches of the river, the work group decided to concentrate its effort on this method.

If the technology could be developed and proved, even in a limited channel reach, it would demonstrate a viable means for managing future channel maintenance dredging. The work group decided to obtain necessary cross sections for the base data and conduct a one-dimensional math model analysis for the length of channel feasible within funding restraints. The

one-dimensional model would provide continuity for future use of the two-dimensional model and improve the confidence and reliability of modified dredging parameters. The cross sections of the effective floodway would also benefit future floodplain modeling efforts. One alternative - to strictly pursue cross-sectional data without one-dimensional analysis beyond one pool - was considered. This alternative would be a productive use of the funding but would not allow as many initial results within the GREAT study period. The work group had sufficient confidence in the one-dimensional math modeling to apply it on a larger scope before testing it on one short reach.

V. SITE SELECTION

The physical and mathematical models could not be applied to the entire 284 miles of channel. Therefore, the work group considered the following reaches for intensive study:

A. Below the Chippewa River (Cairo mile 753.0-763.5), average annual dredging: 222,700 cubic yards.

B. Below Zumbro River - Weaver Bottoms (Cairo mile 742.5-750.2), average annual dredging: 157,200 cubic yards.

C. Pool 7, Black River - Lake Onalaska area (Cairo mile 702.3-714), average annual dredging: 86,900 cubic yards.

D. Below Root River (Cairo mile 687-694), average annual dredging: 136,100 cubic yards.

E. Below Upper Iowa River (Cairo mile 663-672), average annual dredging: 81,700 cubic yards.

The reach above Lake Pepin was eliminated because the dredging quantities were not as great and the sites were difficult to accurately model. The reach below the Wisconsin River was not considered because the dredging requirements are minimal in the GREAT I study reach. The reach downstream of the Wisconsin River was identified as an area worthy of future study to determine what factors caused the minimal dredging requirements for consideration at other sites.

Of the five proposed study reaches, the area at and below the Chippewa River was selected. The factors influencing this decision were:

1. It had the highest average annual dredging requirement.

2. Its environmental sensitivity was comparable to alternative reaches.

3. Physical and mathematical modeling require an estimate of incoming bed load sediment. Because bed load sediment is not carried through Lake Pepin, it was the only site with a known bed load sediment supply on the Mississippi River. This is a significant factor to insure improved analysis reliability.

4. Initial geomorphic and one-dimensional analysis was already in progress at this site. This posed a saving in time and cost.

5. The Chippewa River was being considered for a bank stabilization project by the Corps of Engineers.

It was agreed to concentrate the physical modeling and two-dimensional sediment transport math modeling effort in lower pool 4 but to continue the one-dimensional modeling as far downstream as possible. Requests for one-dimensional modeling all the way to lock and dam 10, Guttenberg, Iowa, would be presented to GREAT.

VI. DEPTH OF DREDGING

A. Introduction

The Mississippi River 9-foot channel project was authorized for construction and maintenance by the 1930 River and Harbor Act. House Document 290 states: "The Congress has authorized and the Secretary of War and Chief of Engineers have directed this board to survey the Mississippi River between the Missouri River and Minneapolis with a view to securing a channel depth of 9 feet at low water with suitable widths." Interpretation of this authority has resulted in use of the project by vessels drafting up to but not exceeding 9 feet.

B. History

Early records of maintenance dredging of the Mississippi River are very limited because only dredging locations, date, and quantity of dredging were recorded before 1956. However, in 1943, dredging to a depth of 11 feet was accomplished at one site to expedite dredging, and dredging to a depth of 15 feet was attempted at another site to reduce frequency of dredging. The average depth after dredging in 1945 was 13.7 feet. Although finite confirmation was not located, it would appear a Mississippi River Board established a dredging depth of 13 feet below LCP levels as the standard for normal 9-foot channel maintenance in 1946. During the period 1946-1973, all channel maintenance dredging on the Mississippi River 9-foot channel was done to 13 feet, with the exception of 1965 and 1969. Extremely large dredging requirements following record flood discharges dictated reducing the depth of dredging to 12 feet below LCP to reestablish the 9-foot channel.

C. Impacts of Depth of Dredging

The depth and width of channel maintenance are viewed as the two most significant factors affecting the quantity of dredging. However, the depth of dredging affects many interrelated features which must be considered to determine the optimum depth. The following factors were identified:

1. Quantity of Dredging. Historically, dredging to a depth of 13 feet has resulted in an average dredging face of 3 feet. Any increase or decrease in depth will significantly affect the quantity initially dredged. Depth of dredging may affect downstream dredging requirements.

2. Frequency of Dredging. The depth of dredging affects the storage capacity for future shoaling. Reducing the depth of dredging could affect the frequency of dredging.

3. Dredging Equipment. Large dredging quantities normally dictate the use of large hydraulic dredges such as the Dredge THOMPSON for time and cost effectiveness. Lower dredging frequencies allow use of the large equipment over greater reaches of the river. Smaller dredging projects with higher frequency could require deployment of an increased number of smaller dredges for time and cost effectiveness.

4. Channel Reliability. The storage capacity of the dredge cut for future shoaling can be affected by the depth of dredging. Sediment transport or shoaling is related to the main stem and tributary discharge. As you reduce the storage capability, the channel can be affected by the sediment

load of frequent intermediate discharges. If the dredging equipment capability is not increased to meet an increase in dredging frequency, channel reliability could be reduced.

5. Width of Channel. Field experience and research conducted by Delft Hydraulics Laboratories indicate the directional stability of the push tow is influenced by the channel cross section. This research indicates that the directional stability is reduced when the depth of channel is less than 1.5 times the draft of the largest vessel.[1] Therefore, as the depth is reduced, a corresponding increase in channel width can compensate for loss of tow directional stability. A reduction in tow velocity also improves tow directional stability within physical limitations.[2]

6. Dredged Material Placement Sites. The depth of dredging can affect the impact of dredging and material placement.

a. Hydraulic Dredging. The depth of face dredged affects the discharge slurry density. Upon reaching a critical depth of face, the slurry density decreases as the areal coverage is limited by mechanical stepping and swing capabilities. Section IV.E.2.h. illustrates

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(1) "Push Tows in Canals," Delft Hydraulics Laboratory, 1975.

(2) J. Boumeester et al., "Recent Studies in Push Towing as a Base for Dimensioning Waterways," Publication 194, Delft Hydraulics Laboratories, Netherlands, November 1977.

this phenomenon in the field pilot tests. As observed in field results, the material placement slopes flatten as the slurry density decreases. A larger area is affected with a given quantity of material as the depth of dredging is reduced with unconfined hydraulic placement. During confined hydraulic placement, the primary areal impacts are related to retention time rather than depth of dredging.

b. Mechanical Dredging. The material placement area affected is determined by the placement method rather than the depth of dredging. The quantity of water handled is affected if the depth of dredging is insufficient to fill the dredge bucket.

7. Commercial Transport Cost. As documented by a University of Michigan research project in 1960, the energy requirement to propel a tow increases as the channel dimensions decrease.[1] Motor vessel travel velocity decreases as the channel depth decreases. Therefore, reductions in dredging depth generally increase commercial product transport cost.

8. Dredging Cost. Higher frequencies of dredging may increase channel maintenance cost. Generally, decreased dredging face will reduce volume productivity but increase areal productivity to an equipment limitation.

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[1] "Resistance of Barge Tows; Model and Prototype Investigation," Civil Works Investigations 814 and 835, Ohio River Division, U.S. Army Corps of Engineers, August 1960.

9. Overall Environmental Impacts. Reduction of dredging quantity will directly reduce the environmental impact of material placement or reduce the cost of avoiding a given environmental impact. Higher frequency, lower volume dredging projects may reduce the size of beneficial use stockpile sites. The Fish and Wildlife Work Group has indicated some benefit to smaller, more frequent material placement because vegetation is better able to recover from several minor successive placements than one large placement. Reduced depth may increase the motor vessel effects on bottom stability, suspended sediments, and turbidity, particularly in fine sediment.

10. Navigational Safety. As reflected in the channel width, the directional stability of the tow is reduced as the channel depth decreases. Representatives of the National River Pilots Association were extremely concerned about the possible effects of reduced channel depths in the approaches to rigid structures such as bridge piers. Any reduction could limit the operators' capability to avoid serious accidents, including losses to life, property, and the environment.

D. Field Pilot Test Criteria

The St. Paul District considered an 11-foot channel depth as stable for navigational use by tows drafting up to 9 feet. Advance channel dredging of an additional 2 feet was done to allow for future shoaling. To gain the cooperation of the St. Paul District in testing the depth

of dredging, field testing of reduced advance channel maintenance was proposed with reduction beyond 11 feet limited to physical and math model examination. The reduced depth testing site selection was based on the recommendation of qualified fluvial hydrologists.

The reduced depth site selection criteria developed by Colorado State University included:

1. Location of Site. A poor location such as immediately above a lock and dam or other hydraulic structures (such as bridges) or in the vicinity of a heavy sediment carrying tributary such as the Chippewa River is considered a negative factor in the analysis.

2. Type of Reach. The straight, divided reach is considered the least desirable location for a reduced-depth dredge cut and an undivided bend the most desirable.

3. Location of the Dredge Cut with Respect to the Thalwag. A cut in alignment with and on the thalweg is considered a positive factor, while location on or near a point bar where there is a readily available source of sediments to refill the cut was considered a negative factor.

4. Stability of Previous Dredge Cuts. Dredge cuts may be eroded or filled at low flow. Filling of a dredge cut under low flow is considered the most undesirable factor; conversely, if historic dredge cuts were stable or eroded during low flow, it would be a positive factor.

5. Dredging Frequency. A high dredging frequency (number of dredging events versus number of years), determined from dredging records, indicates a site which fills easily and is a negative factor. The procedure is to examine the general area in terms of nearby structures and the type of reach, each being accorded a plus, minus, or nothing depending on the criteria outlined above. The dredge cut is examined in detail to determine its location with respect to the thalweg and again accorded a factor. Finally, the dredging history of the site is examined and, in conjunction with the site plan, an attempt is made to determine the stability of previous cuts at low flow and the dredging frequency is recorded. The plus and minus factors are used to determine if regular dredging would be sufficient or if overdepth dredging of 1 or 2 feet should be recommended. A large number of negative factors indicates a greater dredging depth. Positive factors favor reduced depth dredging.

E. Field Investigation and Analysis

1. Scope

a. Field Testing. The Corps of Engineers reduced the depth of dredging (depth of 11 to 12 feet below LCP) at 35 to 49 sites dredged on the Mississippi River during the period 1974-1978. Table 1 illustrates the sites dredged during the program; 1974 was included as base data because dredging depths were reduced even though not sponsored by GREAT. Dredging of small-boat harbors, lock approaches, and back channels was not included because it does not represent the normal navigation channel maintenance condition.

TABLE 1 - MISSISSIPPI RIVER DREDGING HISTORY - ST. PAUL DISTRICT, 1974-1978

Site	Pool	1974 (1)	Qty Dredged/ Qty Deleted (2)(3)	1975 (1)	Qty Dredged/ Qty Deleted	1976 (1)	Qty Dredged/ Qty Deleted	1977 (1)	Qty Dredged Qty Deleted	1978 (1)	Qty Dredged Qty Deleted	Total Qty (4) Dredged	Total Qty (5) Deleted
1. Below Soo Line R.R. Br.	USAF			12	4,118/ 2,000	12	75,429/ 38,000	12	22,934/ 6,700	12	7,823/ 2,100	110,304	48,800
2. Above Lowry Ave. Br.	USAF	13	129,633/ 0	12	16,778/ 8,000	12	8,614/ 2,300			12	3,360/ 1,900	158,385	12,200
3. Above & Below NP R.R. Br.	USAF			12	4,588/ 3,000	12	9,042/ 2,600			12	9,727/ 4,400	23,357	10,000
4. Above & Below Broadway & Plymouth Br.	USAF	13	32,001/ 0	12	13,572/ 8,000	12	22,621/ 6,200	12	9,633/ 3,100	12	9,350/ 6,400	87,183	23,700
5. Above Franklin Ave. Br.	1									12	28,482/ 15,100	28,432	15,100
6. Below Franklin Ave. Br.	1			12	20,032/ 12,000					12	8,159/ 4,600	28,191	16,600
7. Above Lake St. Br.	1			12	65,139/ 18,000	12	10,627/ 4,500	12	10,086/ 4,900	12	224/ 200	86,080	27,600
8. Below Lake St. Br.	1			11	22,312/ 23,000					12	15,287/ 8,300	37,599	31,300
9. Below St. Paul Daymark	1							11	4,477/ 4,100			4,477	4,100
10. Above Lock 1	1			11	28,439/ 23,000	11	6,483/ 7,500			12	7,702/ 4,700	42,624	35,200
11. Above & Below Smith Ave. Br.	2			13	5,128/ 0	13	32,015/ 0	13	1,868/ 0			39,011	0
12. Grey Cloud Slough	2					13	38,414/ 0					38,414	0
13. Robinson's Rocks	2							11	7,894/ 8,650			7,894	8,650
14. Pine Bend Foot Light	2	13	146,938/ 0	12	13,813/ 24,000							160,751	24,000
15. Grey Cloud Landing	2					13	19,189/ 0					19,189	0
16. Boulanger Bend	2	13	236,857/ 0									236,957	0
17. Boulanger Bend Lower Lt.	2	13	137,569/ 0					13	13,265/ 0			150,834	0
18. Above Lock 2	2	13	14,936/ 0									14,936	0
19. Below Lock 2	3	13	32,325/ 0									32,325	0
20. Coulter's Island	3	11	29,050/ 10,000									[illegible]	10,000
21. Trenton, Wisc.	3			11	32,645/ 32,000							32,645	32,000

TABLE 1 - MISSISSIPPI RIVER DREDGING HISTORY - ST. PAUL DISTRICT, 1974-1978

	Site	Pool	1974	Qty Dredged / Qty Deleted	1975	Qty Dredged / Qty Deleted	1976	Qty Dredged / Qty Deleted	1977	Qty Dredged / Qty Deleted	1978	Qty Dredged / Qty Deleted	Total Qty Dredged	Total Qty Deleted
22.	Reads Landing	4	12	60,455/ 15,000	13	105,297/ 0			12	11,206/ 28,740	12/13	140,252/ 40,400	317,210	84,140
23.	Crats Island	4	12	29,044/ 14,000	13	110,371/ 0			11	17,749/ 26,500	12	96,004/ 56,800	253,168	97,300
24.	Above Teepeeota Point	4	11	24,490/ 36,000	13	41,922/ 0							66,412	36,000
25.	Grand Encampment	4							11	3,671/ 4,700			3,671	4,700
26.	Beef Slough	4	11	12,282/ 8,100									12,282	8,100
27.	Male Bend	5	13	45,845/ 0	11	8,324/ 8,000							54,169	8,000
28.	Above West Newton	5									12	12,958/ 8,100	12,958	8,100
29.	Below West Newton	5	13	28,878/ 0	13	16,226/ 0							45,104	0
30.	Fisher Island	5	11	7,343/ 9,500	12	13,933/ 8,000			12	19,740/ 4,900	12	45,437/ 26,300	86,453	48,700
31.	Lower Zumbro	5			12	13,666/ 12,100	12	51,721/ 21,000					65,387	33,000
32.	Mt. Vernon Light	5	13	62,849/ 0									62,849	0
33.	Island 58	5A			11	36,112/ 42,000	11	17,913/ 15,000			11	3,998/ 6,100	58,023	63,100
34.	Head of Betsy Slough	5A					11	10,526/ 18,000			12	10,910/ 3,500	21,436	21,500
35.	Wilds Bend	5A	11	17,127/ 14,000			11	14,534/ 21,100			12/13	33,144/ 41,400	64,805	76,400
36.	Below Lower Winona R.R. Br.	6	13	65,850/ 0			13	37,591/ 0					103,441	0
37.	Below Richmond Island	6			13	41,597/ [illegible],000							41,597	22,000
38.	Winters Landing	7	13	80,569/ 0	0	[illegible]			11/12	25,096/ 18,360	12	25,366/ 13,500	131,031	54,860
39.	Dakota, Minn.	7			11	[illegible]/ 9,000			11	4,357/ 6,200	12	9,666/ 5,900	21,451	21,100
40.	Head of Dresbach Cut	7					12	7,600/ 4,000			12	7,614/ 5,700	15,214	9,700
41.	Above LaCrosse R.R. Br.	7					13	18,248/ 0					18,248	0
42.	Above Brownsville	8	11	11,144/ 9,200	13	23,[illegible]1/ 0					12	11,667/ 9,700	46,222	18,900
43.	Brownsville	8							13	23,973/ 0			23,973	0
44.	Below Head of Raft Channel	8					11	14,047/ 8,600					14,047	8,600

TABLE 1 - MISSISSIPPI RIVER DREDGING HISTORY - ST. PAUL DISTRICT, 1974-1978 (Cont)

Site	Pool	1974(1)	Qty Dredged(2) / Qty Deleted(3)	1975(1)	Qty Dredged / Qty Deleted	1976(1)	Qty Dredged / Qty Deleted	1977(1)	Qty Dredged / Qty Deleted	1978	Qty Dredged / Qty Deleted	Total Qty(4) Dredged	Total Qty(5) Deleted
45. Below Twin Island	9					11	6,200/ 7,700					6,200	7,700
46. Indian Camp Light	9	13	28,178/ 0							11	6,130/ 18,000	34,308	18,000
47. Lansing Upper Light	9	13	31,577/ 0							12	57,294/ 29,000	88,871	29,000
48. Jackson Island	10			13	38,322/ 0							38,322	0
49. Mississippi Gardens						13	25,934/ 0					25,934	0
											TOTAL (1974-78)	3,144,974	979,150

TOTAL QUANTITY AT 13 FEET (6) 4,124,124

FOOTNOTES:

(1) Designated calendar year of dredging. Tabulated data indicated dredging at this site and depth of dredging below low control pool.

(2) Volume of material removed in cubic yards.

(3) Volume of material left in channel by reducing the depth of dredging from historical depth of 13 feet below low control pool in cubic yards.

(4) Volume of material removed from this site 1974-1978.

(5) Volume of material left in channel as a result of reduced dredging depth.

(6) Total Volume of material dredging projected if all dredging during 1974-1978 had been accomplished to 13 feet below low control pool ignoring the impact of dredging depth on frequency of dredging.

b. Dredging Record Analysis. The 1960-1974 dredging record was analyzed to evaluate the impact on individual dredging jobs of modifying dredging parameters to the GREAT pilot conditions. The results are tabulated in table 2. When reviewing this analysis, the reader's attention is drawn to the potential temporary impact of LCP adjustments. The impact of reduced depth dredging on future dredging quantities requires further analysis to avoid potentially erroneous long-term projections.

2. Results

a. Quantity. During the GREAT program (1975-1978), 23 percent, 53 percent, and 24 percent of the dredging based on volume was accomplished to 13, 12 and 11 feet, respectively. During the overall period of 1974-1978, 42 percent, 38 percent, and 20 percent of the dredging was accomplished to 13, 12 and 11 feet, respectively. As previously mentioned, dredging prior to this was normally accomplished to a depth of 13 feet. The GREAT program resulted in an overall reduction of 940,350 cubic yards or 23.7 percent of the main channel maintenance on the Mississippi River 9-foot channel project, based on initial dredging requirements at each site.

Analysis of the 1960-1973 period indicated that reducing the depth to 12 feet would have reduced individual dredging requirements by 25 percent without consideration of impact on frequency of dredging.

TABLE II

PAST [illegible]

EVALUATING IMPACT OF PILOT DREDGING PARAMETERS
DURING GREAT I PERIOD ON DREDGING QUANTITY (1)

Dredging Season (2)	Volume (3) Dredged	Change in LCP (4) Volume	Change in LCP (4) Percent	Reduced Depth (5) Volume	Reduced Depth (5) Percent	New Alignment (6) Volume	New Alignment (6) Percent	Other (7) Volume	Revised (8) Volume	Percent (9) Reduction
1960	1,161,691	-292,779	-25	-317,751	-27	-24,252	-2	0	516,909	[illegible]
1961 (10)	479,608	-37,270	-8	-97,019	-20	+201,346	+42	453	545,665	+14
1962	1,241,192	-193,204	-16	-398,190	-32	-27,509	-2	13,509	622,286	50
1963	1,222,974	-137,776	-11	-332,284	-27	-187,811	-15	107,402	565,103	54
1964	1,077,163	-96,405	-9	-376,945	-36	-309,932	-29	0	293,981	73
1965	2,081,594	-217,978	-11	-454,759	-22	-168,033	[illegible]	321,096	1,240,942	40
1966	2,143,685	-245,491	-12	-447,622	-21	-250,203	-12	18,577	1,200,369	44
1967	1,601,150	-168,336	-11	-415,648	-26	-77,979	-5	10,154	939,297	41
1968	2,486,619	-197,091	-8	-728,007	-29	-651,367	-26	17,406	915,154	[illegible]
1969	1,982,389	-228,108	-12	-61,205	-3	[illegible]	[illegible]	27,036	1,517,286	23
1970	2,262,566	-219,832	-10	-729,372	-32	-254,556	-11	22,980	1,059,906	53
1971	1,737,799	-295,498	-17	-498,673	-29	[illegible],400	-17	43,191	648,219	63
1972	1,879,740	-162,450	-9	-558,856	-30	[illegible],550	-17	3,348	832,884	56
1973	1,726,226	-182,306	-11	-436,929	-25	-208,436	-12	1,364	869,556	49
1974	1,466,510	-211,436	-14	-318,472	-22	-140,320	-10	22,535	796,292	[illegible]
TOTAL	24,549,996	-2,875,860	-12	-6,170,721	-25	-2,574,535	-11	615,954	12,592,704	[illegible]
AVERAGE ANNUAL	1,636,659	-191,724	-12	-411,381	-25	-171,636	-11	41,064	839,514	[illegible]

(1) Analysis does not include potential increased frequency of dredging impact.

(2) Calendar year.

(3) Quantity in cubic yards - ACTUAL.

(4) The minimum water surface projected was revised in 1975. This illustrates the impact of this change if applied to historic dredging. Volume in cubic yards (-) indicates decrease. Impact will likely be temporary rather than long term.

(5) During GREAT, the average depth of dredging was 12 feet below low [illegible] pool. Impact of 12 foot dredging average. Volume in cubic yards. (-) indicates decrease. Impact of 12-foot dredging average. Volume in cubic [illegible]

(6) Tentative channel widths were defined and applied during GREAT. Historic dredge cuts were realigned as necessary to reflect the GREAT conditions, and advance overwidth was restricted to 30 feet. Volume in cubic yards: (-) indicates decrease; (+) indicates increase. Impacts computed following change in LCP and reduced depth to avoid duplicating impacts.

(7) [illegible] dredging such as small boat harbors, backwater dredging, etc., which would not be affected by 9-foot channel dredging depth or width. Volume in cubic yards.

(8) Projected volume of dredging under the GREAT parameters for given year ignoring impact of altering preceding dredging practices. Volume in cubic yards.

(9) (+) indicates percentage increase.

(10) Dredging was limited by equipment availability.

TABLE 3 - FREQUENCY ANALYSIS OF 33 TEST SITES

SITES (1) SUBJECTED TO REDUCED DREDGING	FREQUENCY DREDGING 1956-74 IN %	FREQUENCY DREDGING 1975-78 IN %	AVERAGE ANNUAL QUANTITY CUBIC YARDS 1956-1974	AVERAGE ANNUAL QUANTITY CUBIC YARDS 1975-1978
*1	26	100	15,200	27,600
*2	38	75	11,800	18,100
*3	62	75	Included Above	5,800
*4	31	100	6,000	13,800
5	52	25	20,000	7,100
6	47	50	20,000	7,000
*7	52	100	20,200	21,500
8	52	50	16,200	9,400
9	26	25	2,400	1,100
*10	31	75	9,060	10,600
13	5	25	2,000	2,000
14	31	25	13,300	3,500
21	10	25	8,200	8,200
*22	63	100	79,100	64,200
*23	74	100	59,500	56,000
24	68	25	46,000	10,500
25	31	25	22,200	900
27	26	25	10,300	2,100
28	31	25	19,500	3,200
*30	63	75	44,700	19,800
31	58	50	28,900	16,300
*33	53	75	33,500	14,500
*34	37	50	15,300	5,400
*35	31	50	10,900	11,900
37	31	25	22,520	10,400
*38	21	50	29,000	12,600
*39	42	75	13,400	5,400
*40	26	50	14,600	3,800
42	63	50	41,400	8,800
44	10	25	6,790	3,500
45	0	25	0	1,600
46	37	25	21,200	1,500
47	58	25	41,600	14,300
Ave. Annual Total	39.0	52.3	21,357	12,194
Ave. Annual Asterisked Sites	43.3	76.7	24,150	19,400
Ave. Annual Non-Asterisked Sites	35.4	31.9	19,030	6,189

(1) Site numbers refer to Table I.

The 1956-1974 historical average annual dredging requirement adjusted for 12-foot dredging and current channel alignment was 1,031,239 cubic yards. This represents a reduction of 36 percent in dredging quantity. This comparison is considered optimistic because the base period included record floods in 1965 and 1969 and ignores frequency impacts.

b. Frequency. Table 3 illustrates the pilot program results. The short time frame and potentially nonrepresentative hydrologic cycle are not adequate to gauge individual site long-term impact of reduced depth dredging on frequency. Overall during the GREAT period, on the average, 52 percent of the 33 sites subject to reduced depth dredging were dredged in one year. For these same sites, 39 percent were dredged in an average year for the period 1956-1974, with 13 foot dredging in all but 2 years. This is a 34.1 percent increase in frequency of dredging. Thus, the 42.9-percent decrease in quantity was offset by a 34.1 percent increase in frequency. However, if the test sites are evaluated separately and divided into two groups - 15 asterisked and 18 unasterisked sites shown on Table 3 - an improved perspective is gained.

Dredging increased 77.1 percent at 15 sites marked with asterisks with a dredging quantity decrease of 19.6 percent. At these sites, dredging would be required 3 out of 4 years for reduced-depth dredging versus dredging 2 out of 5 years for 13-foot dredging. The dredging equipment analysis illustrates this is not economically feasible with existing equipment.

Frequency at the other 18 sites decreased 9.9 percent, with a dredging quantity decrease of 67.5 percent. At these sites, a significant decrease in dredging quantity would not increase dredging effort or cost.

Therefore, the impact of reduced-depth dredging on frequency of dredging can be eliminated or minimized if applied on a selective basis.

c. Dredging Equipment Impact. Existing dredging capability was used for maintenance dredging. Additional plant was acquired to allow material placement with longer transport distances. Increases in mobilization, setup time, disposal site shutdown requirements, and mechanical downtime reduced the existing equipment capability. These reductions in capability are not attributable to the depth of dredging. However, it does illustrate that channel maintenance was feasible during 1974-1978 with the reduced depth dredging program. Increased frequency of dredging at the test sites did not exceed existing plant capability. However, because the period of record is short, this conclusion is tempered for long-term or extreme flow conditions.

d. Channel Reliability. During the GREAT period, navigation was restricted at three sites - Reads Landing, Crats Island and Wilds Bend. During the 1974-1978 period, three channel closures occurred at Reads Landing, mile 762.5. Dredging was required twice at Reads Landing, mile 762.5, Crats Island, mile 759, and Wilds Bend, mile 730.5, during the 1978 navigation season. Before GREAT, channel closures occurred at Reads Landing, and dredging has been required twice annually in one location but never with the frequency encountered during the test period. An analysis of these site conditions is therefore provided:

1. <u>Reads Landing</u>. The record at Reads Landing was:

Date	Event	Dredging Depth (Feet)	Quantity (Cubic Yards)
31 May 1972	Dredging	13	52,444
5 July 1974	Closure		
3-11 July 1974	Dredging	12	60,455
9-19 June 1975	Dredging	13	105,297
28 March 1977	Grounding		
30 March-4 April 1977	Dredging	12	10,350
7 April 1977	Grounding		
7 April 1977	Dredging	12	856
21 May 1978	Closure		
24-30 May 1978	Dredging	12/13	96,640
10-18 August 1978	Dredging	12	43,612

The closure of Reads Landing in 1974 would normally have been avoided. The Corps of Engineers delayed dredging to comply with a court-ordered notification period and scheduled alternate dredging to avoid a shutdown of the Dredge THOMPSON. This closure was not related to reduced-depth dredging.

Channel condition surveys in 1976 following the 13-foot dredging in 1975 showed an excellent channel until September. The channel was marginal from September through the close of navigation. Surveys indicated a 450-foot

width greater than 9 feet, a 420-foot width greater than 10 feet, but only a 50-foot width greater than 11 feet. Emergency dredging was required the next spring when the first tow through the St. Paul District grounded. An emergency 200-foot channel was dredged to 12 feet by the Derrickbarge HAUSER in April 1977. Channel widening with the THOMPSON was not required because the channel improved through natural river scour. Reduced-depth dredging was not responsible for the difficulty but may have contributed.

Sonar surveys conducted twice in April 1978 indicated that the channel was in excellent condition. Rapid shoaling in early to mid-May 1978 resulted in the May 1978 closure.

In summary, reduced depth dredging had very little direct impact on the closure frequency during 1974-1978 at Reads Landing. Preliminary results of the physical model indicate that channel reliability can be improved through monitoring of the Chippewa River delta (see Section XII.C.).

2. Crats Island (near Wabasha, Minnesota). Crats Island was dredged to 12 feet in 1974, 13 feet in 1975, 11 feet in 1977, and 12 feet twice in 1978. The shoaling and dredging requirements similarity between Reads Landing and Crats Island is obvious during the 1974-1978 period. A channel closure was imminent at Crats Island in June 1978, but emergency dredging with excellent industry cooperation restored the channel. Dredging was required annually with reduced-depth dredging, and the integrity of navigation was threatened in 1977 and 1978. Of all the sites reviewed, Crats Island was the least successful. The 1974-1978 field record indicates that dredging to depths less than 12 feet is unacceptable. Alternate means

of reducing dredging quantity should be pursued at Crats Island as discussed in Section VII.

3. Wilds Bend. Dredging was accomplished to 11 feet in 1974, 11 feet in 1976, and twice in 1978 to 13 feet initially and finally to 11 feet. Because Wilds Bend was initially dredged to 13 feet in 1978, the 1978 frequency cannot be attributed to reduced-depth dredging. However, the reduced depth dredging study at Wilds Bend showed that the average annual dredging requirement remained constant with a frequency of dredging increase of 50 percent. It was not viewed as a hazard to the reliability of the channel but ineffective in reducing quantity with a significant increase in cost.

4. Other Test Sites. The channel reliability was not affected under the test hydrologic conditions.

In summary, the field records for 1974-1978 do not indicate an increase in channel closures with reduced-depth dredging. The channel reliability was threatened at Crats Island without any benefit to reduced dredging quantity. A much greater risk of channel closure results particularly with 11-foot versus 12- or 13-foot dredging for the following reasons. Field documentation has shown that channel closure can occur within a few days of the channel reaching a depth of 10 feet. The 1974 closure at Reads Landing demonstrated that the channel closed within 4 days with channel depths not less than 10 feet without any change in river stage.

When dredging is limited to 11 feet, the Corps of Engineers, St. Paul District, hesitates to initiate dredging when isolated depths at a site approach 10 feet. It costs many thousands of dollars to improve the channel depth a few tenths of a foot with existing equipment. Channel maintenance as exemplified by Reads Landing in late 1976 is deferred with increased site monitoring. In this case, the risk to the channel reliability is definitely increased. Development of equipment with high efficiency in dredging an extremely shallow face of material would improve the viability of reduced depth dredging. In addition, development of capability to predict whether the site will continue to shoal shallower or scour deeper would help define dredging needs. This predictive and equipment capability would minimize dredging cost, and quantities dredged and improve the channel reliability.

e. Width of Channel. In general, channel widths were not increased to allow for the decreased tow stability encountered with reduced depth dredging. The impact can only be addressed by the Commercial Transportation Work Group.

f. Dredged Material Placement Sites. Individual projects with varied depth of dredging were not accomplished to document the impact of dredging depth on the placement site. However, with uncontained hydraulic dredging, flatter back slopes were encountered with reduced depth dredging. It appeared in specific instances such as above Brownsville (pool 8) and Indian Camp Light (pool 9) that more material was scoured from existing

13-foot dredging sites than was retained on land. In contained hydraulic dredging, additional dike maintenance was required with reduced-depth dredging. These impacts resulted from a lower slurry solids ratio and do not apply to derrickbarge dredging.

g. Commercial Transport Cost. The Commercial Transportation Work Group attempted to identify the impact of reduced depth dredging on shipping cost. Based on a 1960 study conducted by the University of Michigan, Department of Naval Architecture and Marine Engineering, entitled "Resistance of Barge Tows", a 300-foot channel 11 feet deep (compared to 13.5 feet deep) reduces tow speed 12.7 percent and increases the energy consumption to maintain a constant speed 23.8 percent. The St. Paul District dredges 5.7 percent of the channel annually and has historically dredged 28.5 percent of the channel at least once. The long-term effect on the overall navigation channel condition cannot be determined with existing technology.

h. Dredging Cost. The past 5 years' performance of the THOMPSON and HAUSER was analyzed to determine the impact of reduced depth dredging. The cost can be increased if the frequency of dredging increases. In both examinations, only actual dredging time was considered to minimize the impact of placement site conditions on overall productivity. Alternate equipment could not be evaluated because the THOMPSON and HAUSER accomplished all pilot efforts.

(1) Dredge THOMPSON. The following tabulation illustrates the THOMPSON without application of the Boosterbarge MULLEN with dredging initiated when the channel depth reached 10.5 feet.

Dredging Depth (Feet)	Average Face (Feet)	Production/Pumping Hour Sq. Yds./Hr.	Cu. Yds./Hr.
11	1.32	1341	589
12	1.77	1347	794
13	2.90	982	948

These figures clearly indicate that the average 11 foot project costs the same as the average 12 foot project because the areal production is constant. Therefore, it is just as economical to dredge to 12 feet as 11 feet with the THOMPSON; any increase in frequency increases the cost. The areal production drops considerably with 13-foot dredging, and an increase in frequency is acceptable. Assuming an average mobilization of 2 days with an average job requirement of 4 days with 13-foot dredging, the frequency of dredging at 12 feet could increase 22 percent without reducing the cost effectiveness of the THOMPSON. Use of a 20 percent factor is recommended because the average face at 12 feet may increase. The production of the THOMPSON with the Boosterbarge MULLEN was slightly higher, but significant mobilization and setup time is an overriding factor.

(2) Derrickbarge HAUSER. A similar tabulation for the HAUSER is:

Dredging Depth (Feet)	Average Face (Feet)	Production/Dredging Hour Sq. Yd./Hr.	Cu. Yds./Hr.
11	1.81	288	174
12	2.50	230	192
13	3.67	166	202

Considering the areal production data, an average job size of 9 days at 13 feet, 1 day of mobilization, and 10 percent stepping time, the frequency of dredging could increase 28 percent with 12-foot dredging and 52 percent with 11-foot dredging without increasing the dredging cost.

A trial effort was made to improve the production of the HAUSER in shallow face dredging. The clamshell will take up to a 2-foot face in a single pass. When the face is less than 2 feet, the clamshell is only partially loaded, but the cycle time remains nearly uniform. Therefore, a concept of dredging a cut face 1-foot deep by dredging 2 feet deep but skipping 50 percent of the area in a checkerboard pattern was considered. This method was tested on the outside cut of below the head of Raft Channel (pool 8) in 1976. The dredge cut was on the inside of a river bend. The HAUSER production increased, but unfortunately the dredged area did not level out. It remained uneven throughout the balance of the 1976 season. The river flow was insufficient to level the area, and the motor vessel propeller wash was not effective because it was directed to the outside of the bend. Any future attempt should include trial application of a drag bar or beam to level the area.

Additional testing on crossover or tangent river sections appears warranted.

i. Environmental Impact. This work group did not attempt to evaluate the environmental impact of lower volume, higher frequency material placement.

j. Navigational Safety. Test sites for reduced depth dredging generally avoided areas where rigid structures formed the channel boundaries. During 1978, serious accidents occurred at Wilds Bend - Betsy Slough (pool 5A) and Lansing Upper Light (pool 9). Both sites involved channel condition and are discussed in the channel width section. Reduced depth dredging was not considered applicable to either site.

This work group recognizes that reduced depth dredging affects the capabilities of a motor vessel and tow handling characteristics. Therefore, where the safety of the motor vessel and its cargo are endangered by rigid structures forming the channel boundaries, safety should be the governing factor in determining depth of dredging.

F. Conclusions and Recommendations

1. Reduced depth dredging was very successful in minimizing dredging quantity at suitable sites. The 42.9 percent reduction at actual pilot test sites from 1975-1978 demonstrates the effectiveness to date.

A 67.5-percent reduction was obtained at selected sites (those not marked with an asterisk). The value judgment weighing the cost and navigational impacts against the potential quantity reduction benefit should be made by GREAT and will not be assessed by this work group.

2. A thorough literature search and necessary supplemental research is recommended to determine the necessary channel width to maintain navigational safety under varying conditions. The definition should allow for variation in physical factors such as channel depth, degree of curvature, river velocity, outdraft, wind, etc.

3. Average annual dredging quantities should be minimized through application of technically-supported reduced depths and minimum channel widths suitable for navigation with exception for other specific recommendations.

4. Reduced-depth dredging should be avoided when it increases the frequency of dredging without a decrease in average annual dredging quantities. Exception resulting from placement area restraints could be encountered.

5. Dredging depths in approaches to rigid structures such as locks, bridges, piers, or other structures which pose potential safety hazards should be determined by technically-supported safety criteria rather than by minimizing dredging quantities.

6. Whenever beneficial use demand exceeds dredging requirements or an individual demand will be unavailable in the future, dredging depth and width should be based on channel maintenance and navigational economy. In these instances, minimizing dredging quantity to minimize placement site impact is unnecessary.

7. Reassessment of the 1960–1974 dredging period using revised parameters indicates that average annual dredging quantity could be reduced to 900,000 to 950,000 cubic yards. This analysis did not allow consideration of increased frequency of dredging. However, the last 4 years of the GREAT pilot operations have consistently resulted in less than 800,000 cubic yards of dredging. Special attention is drawn to the estimate of peak dredging requirements of 1.5 million cubic yards shown on table 2 which affects equipment capability needs.

VII. WIDTH OF DREDGING

A. Introduction

The enabling legislation for the 9-foot channel project directed the Corps to construct the project to secure a channel depth of 9 feet at low water with suitable widths.

Congress left river bend widths to be determined by the Corps. The GREAT study framework includes continuation of the existing navigation system. In reviewing channel width, this work group considered the maximum tow size operating on the Upper Mississippi River as 107.5 feet wide by 1200 feet long, drafting up to 9 feet. Channel widths up to 550 feet were maintained on river bends, and over-width or advance dredging was accomplished as equipment and funding capabilities allowed. The Dredging Requirements Work Group decided to attempt to determine the width of the channel required for navigation and review the feasibility of minimizing advance dredging in an attempt to reduce dredging quantities.

B. Determination of Channel Bend Widths Required for Navigation

1. Alternatives. Four methods of obtaining an estimated width were considered:

a. Mathematical Computation. The width of channel required by a theoretical computation as noted in the 24th International Navigational Congress has many variables. The theory assumes a constant cross section,

a radius of bend which is constant throughout the bend, excellent visibility and pilot capability to maintain the center of gravity of the tow on the centerline of the river bend axis, and no crosscurrents caused by incoming or outgoing channels. Variables in the equation include radius of bend, length of tow, location of the center of mass of the tow, shape of the tow, river velocity, tow velocity, motor vessel rudder force, width of tow, draft of tow, motor vessel propelling characteristics, tow mass, depth of channel, total river surface width and angle of current velocity to tow longitudinal direction, etc. It quickly became evident that the work group could not develop a theoretical computation for the reach of river involved which would consider all conditions.

b. Physical Modeling. This method was beyond the funding capability of the GREAT program because each 1- to 2-mile reach would cost over $100,000. The Corps of Engineers Waterways Experiment Station (WES) is conducting physical modeling efforts to provide general guidelines. Up-to-date results of the WES effort are provided in this section's conclusions.

c. Monitoring a Test Tow. This method would include providing instrumentation on an existing vessel and would study the vessel's passage through actual field sites. This procedure would be very difficult because the worst conditions could not be studied in the limited time frame throughout the District. This method was also beyond funding capability.

d. Survey of Experienced Pilots. This method appeared the most viable because the pilots would be in a position to observe varying conditions throughout the District. The primary objection to this approach centered on the objectivity and credibility of the pilots because they have a self-serving conflict of interest.

2. Selection. The work group decided to request the assistance of the Commercial Transportation Work Group (CTWG) to determine, through a pilot survey, the estimated width. To allow realistic appraisal of the river bend width, the normal width prior to dredging, normal width after dredging, width of bend at the last channel condition survey and maximum potential width without structural modifications were provided as base data. In consideration of the potential hesitancy of the pilots to recommend a change that might prove unrealistic in practice, the recommendations would only be used for potential testing by the Corps. Further adjustments would be expected based on experience. A formal request was forwarded to the CTWG in September 1976.

3. Result. Table 4 provides a tabulation of the base data provided to the CTWG and the suggested widths. These recommendations were compiled considering the following conditions:

a. Any recommended changes would be implemented, if possible, and would be revised, based on motor vessel operator experiences.

b. Channel width should only provide for one-way traffic on river bends.

c. Channel width should be adequate to allow navigation under all conditions.

d. Channel width should be sufficient to allow a realistic tolerance for clearance of wing dams, other fixed obstacles, and shallow water for safe operation of tows.

e. Additional width to allow for interim shoaling between dredging periods will not be considered.

The results included recommendations of 17 bend width reductions and 9 bend width increases. This illustrates a high objectivity by the pilots. The pilots and CTWG are commended for their effort and cooperation. One criticism of this method was received verbally stating "only experienced pilots were surveyed, and less-experienced pilots may require additional width."

C. Field Testing and Analysis

1. Implementation. The Corps was asked to consider the results of the Motor Vessel Operators survey and field test the recommendations. In addition, the St. Paul District was requested to minimize the over-width or advance dredging at each site. In practice, advance dredging was restricted to 25 - 50 feet in addition to the recommended width that best fit the channel alignment. All recommendations were followed in laying out dredge cuts, except the recommended channel widening at Reads Landing.

2. Results. Evaluation of the impact on dredging quantity was very difficult to ascertain during the 1977-1978 test period because it would have to include an assumed over-width dredging quantity. Therefore, the impact was computed as an overall quantity with the reduced depth dredging section. However, to obtain an insight on the impact of both the suggested widths and reduced overwidth dredging, the 1960-1974 period of record was examined. This approach does not allow consideration of the impact of potential increased frequency of dredging. After adjusting the 1960-1974 quantities for the revised 1975 low control pool and an average 1-foot reduction in dredging depth, an average decrease in annual dredging quantity of 11 percent, or 171,000 cubic yards, was determined. Table 2 illustrates the annual and overall impact ignoring the potential impact of increased frequency of dredging.

D. Conclusions

1. The reduced overwidth dredging should be continued with monitoring to assure that the long-term impact is beneficial.

2. Application of the pilot-suggested widths should be continued with annual surveys of the users to assure testing of further reductions, which are recommended, and reestablishment of additional width where the reduction is excessive.

3. Appendix 1 provides the preliminary results of the Waterway Experiment Station general guidelines for determining channel bend widths. It should be noted this width does not allow for clearance, outdraft, wind, etc., but only estimates the vessel width required. It is also based on an 8-foot vessel draft.

4. A committee should be established to review channel dimensions. The committee could be led by the Corps with representatives from the Coast Guard, navigation industry, and technically qualified representatives from any other concerned State or Federal agencies.

5. Because tow size is a significant factor in channel width and maintenance requirements, it is recommended that the Corps or Coast Guard establish a regulation requiring advance approval for use of a tow size larger than 107.5 feet wide or 1200 feet long in the St. Paul District. This regulation would recognize the existing operator liability for any damage to the channel condition. If an increase in tow size is proposed for use other than trial application and would require additional channel width, the Corps of Engineers should prepare an Environmental Impact Statement (EIS) because increased channel width maintenance is considered to be a major Federal action. The quantitative impact of increased tow dimensions was not analyzed by this work group. It is recognized that an EIS would probably be required to allow cnstruction of lock guidewall extension by the Corps of Engineers, but use of "bow thrusters", motor vessel assistance at the locks, or other methods might be considered by the shipping industry if economically feasible.

6. During the 1978 navigation season, significant groundings with property and/or environmental damage occurred at Wilds Bend - Betsy Slough (pool 5A) and at Lansing Upper Light (pool 9). Reduced channel width

would appear to be a major factor in these groundings. The Corps, with the cooperation of the State and Federal regulatory agencies, should expedite the maintenance dredging program when the suggested widths are restricted. Warnings to mariners should be announced through the existing Coast Guard system when the 9-foot channel widths are reduced in excess of 10 percent from the required tangent width or suggested bend width.

VIII. INITIATION OF DREDGING

A. Introduction

Before GREAT, the Corps scheduled and/or accomplished channel maintenance when the depth reached 11 feet or less below LCP. Channel closures have occurred without additional shoaling when the channel depth reached 10 feet. The 11-foot criterion assumes that the channel will continue shoaling beyond 11 feet to closure. The Dredging Requirements Work Group was concerned that channel conditions could stabilize at or near 11 feet, thereby resulting in nonproductive dredging.

B. Field Study

As requested by GREAT, the Corps of Engineers, St. Paul District, modified its criteria to only program and/or accomplish channel maintenance when the depth reached 10.5 feet below LCP. This pilot program proved very successful during the 1975-1978 period, except at Reads Landing in 1976-1977. Dredging was avoided or at least deferred at Grand Encampment (pool 4), Homer, Minnesota (pool 6) and above Brownsville (pool 8).

C. Conclusions and Recommendations

1. During the GREAT test period, advance coordination of channel maintenance was a continuing problem. Therefore, as an interim measure, the Corps should initiate coordination of a dredged material placement

site and apply for appropriate permits for specific maintenance projects no later than when the channel reaches a depth of 11 feet or less below LCP. When GREAT-approved channel maintenance is implemented, advance coordination difficulties would have been resolved.

2. Channel maintenance dredging should be deferred until the channel depth reaches a depth of 10.5 feet below LCP with the following exceptions:

a. Approaches to structures which form the channel boundary. The initiating depth should be determined by the channel dimension committee in the interest of safety.

b. Sites which constitute sediment traps and which will not stabilize naturally. Specific sites include head of navigation on the Minnesota and Mississippi Rivers, the St. Paul Barge Terminal, and the head of Lake Pepin.

c. Sites which have a history of closing navigation. At this time, these sites would be Reads Landing and Crats Island in pool 4. The factors controlling the river sedimentation should be analyzed to develop a forecasting system for sites such as these.

d. If technical analysis illustrates that the channel will remain stable or become deeper, dredging should be delayed, with continued monitoring of the condition of the channel.

IX. STRUCTURAL MODIFICATIONS TO REDUCE DREDGING QUANTITIES

A. Wing Dams and Closing Dams - Mississippi River

1. The Existing 9-Foot Channel System. This system includes wing dams and closing dams that were designed to retain the river flow in the navigation channel during low-flow periods. These structures increase the flow and velocity in the channel and allow increased natural riverbed scour to minimize dredging requirements.

2. Field Surveys. The Corps reviewed existing records and alerted its field crews to note evidence of wing dam and closing dam deterioration. The wing dam pattern and/or alignment was briefly reviewed to identify sites with obvious design review requirements.

3. Conclusions.

a. The following wing dams or closing dams showed significant evidence of deterioration:

Pool	Mile	Bank	Description
4	759.2	RB	Dam 2
4	756.8	LB	Dams 56 and 57
5	750.0	RB	Closing dam 4
5	746.6	LB	Roebucks Cut
5	745.7	LB	Closing dam 41
5A	736.5	RB	Dams 1 and 74
5A	732.0	RB	Closing dam 60

Pool	Mile	Bank	Description
6	728.0	LB	Wing dam 87
6	724.3	LB	Wing dams 64-67
7	711.6	LB	Closing dam 8
7	706.8	RB	Dams 42 and 36
7	705.2	LB	Dam 72
8	688.3	LB	Wing dams
9	666.9	LB	Closing dam 6

b. The following sites have been identified as areas which should receive further study to determine if the suggested modifications to the wing dams might reduce dredging requirements, if some other modification might be better, or if the existing situation should be maintained:

(1) River mile 745.5 - Below West Newton - Add one or two wing dams along the right bank, across the channel from wing dam 55, and below the existing wing dam on the right bank.

(2) River mile 730.4 - 732.0 - Betsy Slough, Wilds Bend - In this reach, remove or shorten wing dam 66 (mile 732.0, left bank), add two dams on the left bank at approximate river miles 731.4 and 731.2, shorten wing dam 88 (mile 730.4-730.7, left bank), and add one wing dam on the right bank at river mile 730.8.

(3) Mile 713.0-713.5 - Above Richmond Island - The existing wing dams along both banks should be extended.

(4) Mile 706.7-709.0 - Dakota, Minnesota, and Winters Landing - Shorten wing dams 18 and 30 (mile 709.1-709.2, left bank), and extend wing dam 19 (mile 708.3, left bank) downstream toward the dam identified as "Mound of Riprap Top El. 652.0" (mile 707.9, left bank). Shorten wing dams 42 and 43 (mile 706.8-706.9, right bank). Wing dams, right bank (mile 708-709) appear to be ineffective because a deep channel runs through the field.

(5) Mile 690.5 - Above Brownsville - At this site, shorten wing dam 65 (left bank) and lengthen wing dam 33 (right bank).

(6) Mile 664.6-774.7 - Lansing Upper Light - Remove or shorten wing dam 13 (mile 664.7, left bank), and add a wing dam on the right bank (approximate mile 664.7).

c. During the course of this study, three sites were noted - mile 694.1-694.7, mile 657.3-657.5 (left bank), and mile 618.0-618.3 (left bank) - which could be improved by building up or repairing the bank protection shown on the sounding sheets.

4. Recommendations. Investigate the condition of all wing dams and closing dams at all historic dredging sites in the St. Paul District. Consider repair and/or modification based on one-dimensional sediment transport math modeling. Develop specific site recommendations for individual sites using more sophisticated math or physical modeling,

if necessary. Considering future deterioration and impact on dredging quantity and disposal at long-range disposal sites identified by GREAT and the net environmental impact, the Corps should request funding and program any justified rehabilitation. Even if the sediment is only retained in the system until it reaches a suitable placement site, the effort may be justified.

B. Tributary Sediment Control - Sediment Traps

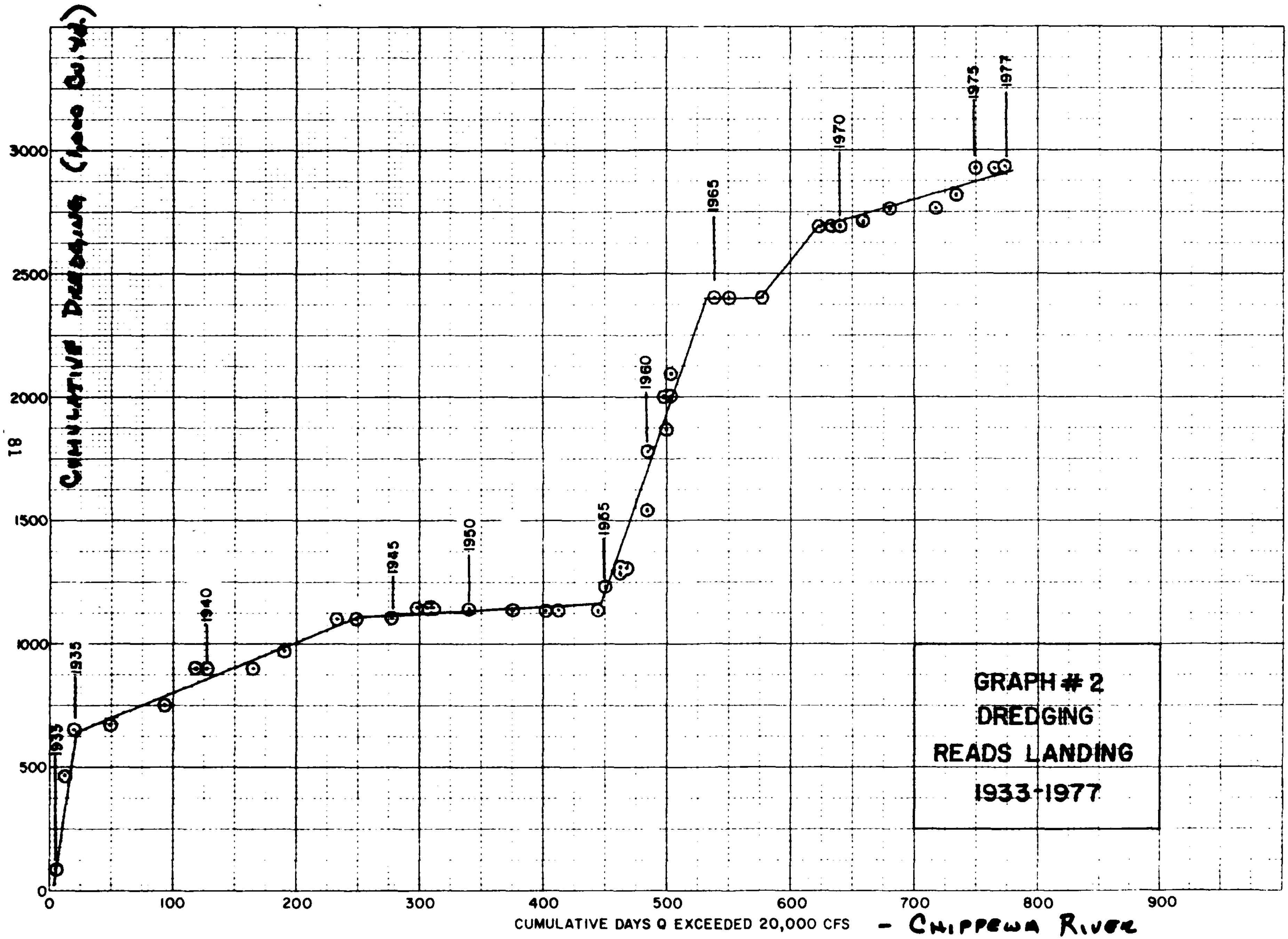
1. Introduction. The quantity and grain size of sediment a river can carry downstream increases geometrically with the current velocity. The velocity can be reduced by increasing the river's cross-sectional area. This slowing of a tributary river velocity would potentially allow sediment deposition in the tributary before the sediment reaches the Mississippi River channel. Trapping sediment in the tributaries is an alternative to dredging the main channel. Two methods are being evaluated on the Chippewa River using physical and mathematical models: (1) a low-head dam on the Chippewa River to reduce the flow velocity by raising the water surface and (2) excavation of a stilling basin which lowers the channel bed, thereby reducing the flow velocity.

2. Historical Record Evaluation.

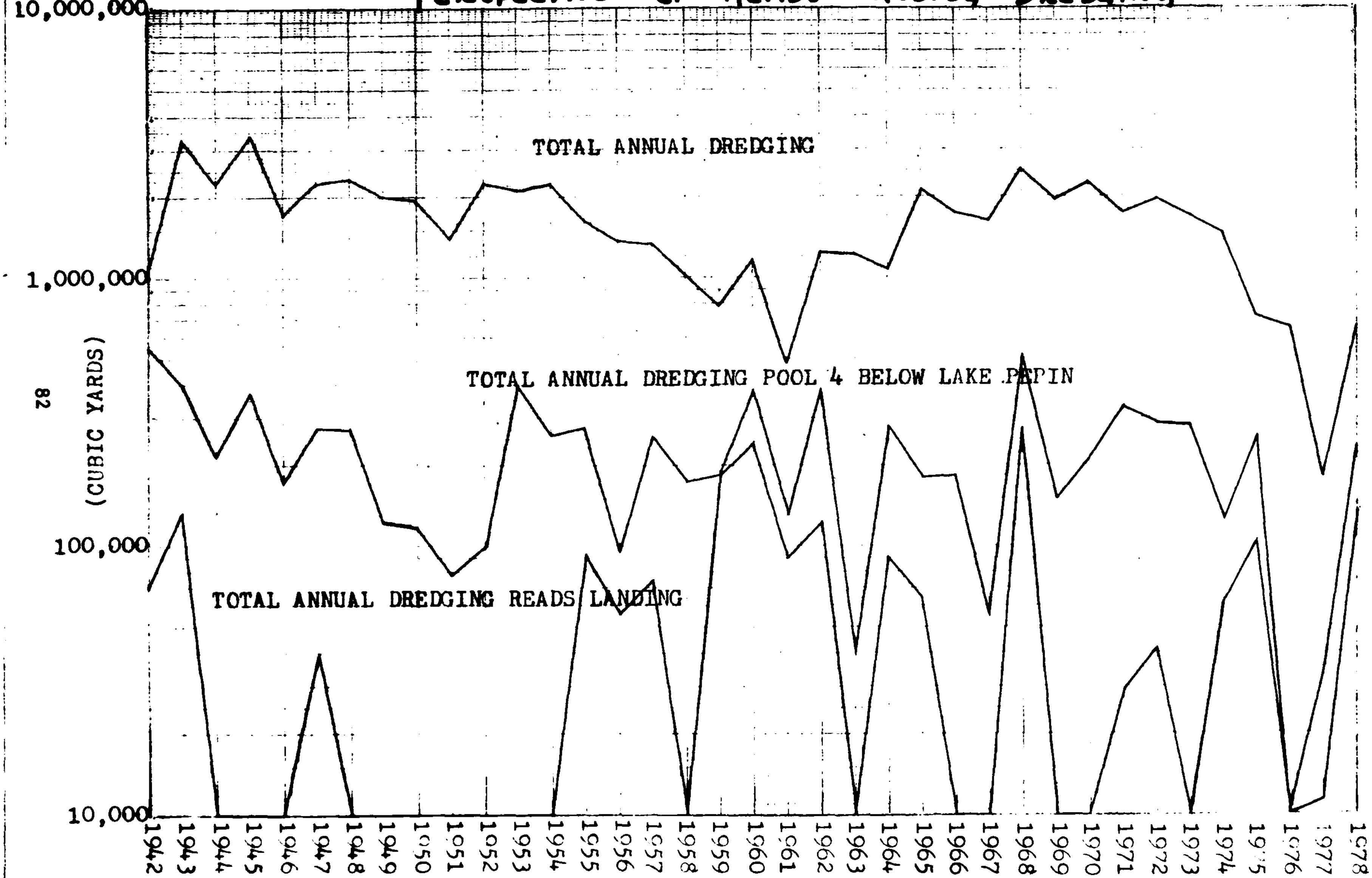
a. Impact of Establishing Pool 4 on Dredging. Graph 3 illustrates the channel maintenance dredging quantity in pool 4 below Lake Pepin and Reads Landing, during the period 1942-1978. The graph shows that only 39,000 cubic yards of dredging was required from 1944-1954 at Reads Landing. This represents an average annual requirement of 3,500 cubic yards. During the period 1955-1978, an average annual quantity of

77,100 cubic yards of dredging was required. Graph 2 illustrates the cumulative dredging at Reads Landing as related to the days when the Chippewa River flow is above 20,000 cubic feet per second. This graph illustrates varying sustained trends of dredging at Reads Landing with one exception in 1965-1967. This phenomonen is covered in the impact of a sediment trap on dredging. Graph 3 creates concern that the total dredging in lower pool 4 did not reduce significantly during 1944-1954 when Reads Landing dredging was minimal. A hypothesis is offered that the river flow through Lake Pepin may have borrowed sediment from the Mississippi River bed above Wabasha, Minnesota, when the Chippewa River sediment supply was minimal, resulting in near normal total dredging in lower pool 4. If this river response would hold true, eliminating most of the Chippewa River sediment may only be locally beneficial for an extended period. Silting investigations from 1935 through 1962 indicate aggradation of the Chippewa River following creation of pool 4, However, the impact of creating pool 4 is not clearly evident at Reads Landing or lower pool 4 in the historic records.

b. Impact of Sediment Trap on Dredging. A sediment trap of 313,800 cubic yards was dredged on the Chippewa River in May 1965. The trap was dredged to catch the sediment before it reached the Mississippi River. An area of 780,000 square feet was deepened from approximately 9 feet to 20 feet. The site was located 2,400 to 4,000 feet upstream of the Chippewa River confluence with the Mississippi River channel. Monitoring of the sediment trap showed the area had filled by the fall of 1966. Initial reaction was unfavorable because of the short life of the trap. However, dredging was not required at Reads Landing in 1966 and 1967 under normal flow conditions. Dredging requirements in lower pool 4 in 1967 dipped 95,000


GRAPH # 2
DREDGING
READS LANDING
1933-1977
CUMULATIVE DREDGING (1,000 CU. YD.)
CUMULATIVE DAYS Q EXCEEDED 20,000 CFS - CHIPPEWA RIVER
0
500
1000
1500
2000
2500
3000
100
200
300
400
500
600
700
800
900
1933
1935
1940
1945
1950
1955
1960
1965
1970
1975
1977

Perspective of Reads Landing Dredging



cubic yards below average annual requirements. Graph 1 illustrates the definite valley in dredging requirements. The cubic yards dredged for 1963, 1976, and 1977 correlate very well with low-flow periods.

3. Recommendations.

a. Construction of low-head dams to create more favorable tributary river stage in relation to Mississippi River stages should be investigated. This is being accomplished for the Chippewa River.

b. A sediment trap should be established on the Chippewa River and on other tributaries if feasible and economically justified, based on the 1965 Chippewa River test and initial physical modeling effort reported later in this report.

X. CHANNEL ALIGNMENT DEFINITION

A. Introduction

The 9-foot channel is marked by the Coast Guard with a system of temporary and permanent navigation aids. Permanent piers are located to define the general channel alignment maintained by the wing dam and closing dam system. Thousands of temporary aids consisting of buoys anchored with cable and concrete weights are provided to allow a more exacting channel definition. The buoys are placed as guides, but any operator repetitively running aground outside the buoy line is subject to severe disciplinary action by his company and potential loss of his license to operate by the Coast Guard. The buoys are generally placed to reflect the 9-foot channel border at low control pool. The quantity of buoys currently defy Coast Guard adjustment to river stage. The Coast Guard has a tremendous task to maintain the system at present with the ever-changing condition. Every spring, the buoys require adjustment because many are displaced by ice action.

B. Dredging Requirements Work Group (DRWG) Concern

During early navigation in March and April, many buoys are off station. The Coast Guard has one buoy tender, the WAYACONDA, to maintain over 500 miles of channel aids on the Upper Mississippi River. Many early spring groundings occur because the buoy system is unreliable. This poses a hazard to the channel and to the environment should a containment spill occur. As river stages and current increase, additional channel width is required on river bends. No

feasible system to adjust the buoys to reflect the additional channel depth and width available is known. Currently, motor vessels can only use the additional channel width beyond the buoy line at their own risk. If a feasible method was ever developed, the Corps could reduce river bend width maintenance.

A third concern noted is that many permanent navigation aids are exposed to possible loss from ice action. Additional appropriations for riprap protection would appear justified.

C. Recommendations

1. The Coast Guard's capability to operate and maintain the navigational aid system. Serious groundings and property damages such as occurred at Dakota, Minnesota, in 1978 could be avoided, and a significant increase in navigational safety would be gained. The DRWG recognizes the good faith effort of the Coast Guard but offers this recommendation as support to any 2nd Coast Guard District request for additional navigational aid system maintenance.

2. If a system is developed to allow buoy adjustment to reflect available navigation channel with changing river stages, the benefits of reduced maintenance dredging requirements should be compiled as a system justification.

XI. USE OF RIVER SEDIMENT TRANSPORT CAPABILITY

A. Riverine Placement

1. Introduction. The Mississippi River transports large quantities of sediment that are never dredged. The late Dr. Al Anderson of the University of Minnesota approached the work group with the possibility of returning the sediment to the river system for natural digestion and transport through the system. To provide an idea of magnitude of natural sediment transport, the Rock Island District observed and documented a net loss of approximately 500,000 cubic yards of material from 0.75 mile of channel in a 6-week period. This concept met much opposition because of possible downstream channel and backwater effects on navigation and fish and wildlife values and the potential impact on water quality.

2. Field Testing. In June 1975, a pilot test of riverine placement was conducted at Reads Landing. Approximately 11,000 cubic yards of material was placed in a deep water pool downstream of the dredge cut. The material was pumped through a 90° elbow from the THOMPSON pipeline and released approximately 1 foot below the water surface to minimize visual objections. The deepwater area was surveyed before placement, after placement, and after July 1975 high water. The following results were noted:

a. The material accumulated so rapidly that the channel condition was endangered by this method. Future efforts should include spreading over the surface to aid dispersement.

b. The July 1975 high water leveled the area.

c. The impact could not be measured in the fall and spring surveys at the pool or the next downstream dredging site at Crats Island. Further field testing was not attempted because of team opposition, and further consideration has been deferred to physical and math model testing.

3. Recommendation. Riverine disposal should be investigated for adoption where recommended beneficial uses are unavailable and where secondary environmental impacts of riverine placement are less than alternate placement sites. Field tests would be limited to small quantities of clean, tracer materials.

B. Modification of Shoaling Pattern

1. Introduction. Modification of the wing dam system has the potential of dictating where shoaling occurs. Wing dam designs might be improved at desired sites to improve the river velocity and sediment transport through critical locations where dredging and material placement are undesirable. Removal or modification of the existing wing dams could reduce the river velocity and sediment deposition at other sites where dredging and material placement are more advantageous. This could prove effective to reduce dredged material transport cost to reach desired placement sites. Investigation would be limited to physical and math model testing because field testing is too costly.

XII. CONTRACT EFFORT AND INITIAL RESULTS

A. General

One purpose of the DRWG was to develop recommended criteria and alternatives for maintenance dredging parameters to minimize the total dredging quantities without loss of the integrity of the 9-foot navigation project on the Upper Mississippi River. Contract efforts are intended to provide the technical basis needed to justify, with confidence, adjustments in the maintenance program that will provide the 9-foot channel at minimum economic and environmental cost. Some of the contract efforts by other work groups and agencies within GREAT can also be used to evaluate dredging alternatives and modifications. In October 1979, final reports and results had not been obtained from all of the Work Group's contracts. For these contracts, only the initial results and conclusions will be presented, and they could change.

The contracting effort can be divided into two groups: physical and mathematical modeling. Physical modeling consists of two contracts to the University of Minnesota, Minneapolis, Minnesota. The first contract studied the performance of various submerged groin configurations in providing the desired bed profile. This contract was completed, and a final report was published in March 1976. The second contract was for a physical model of the confluence of the Chippewa and Mississippi Rivers. The purpose of this study was twofold: to provide data needed to calibrate the two-dimensional

mathematical model and to generate some data, independent of the mathematical model, which can be used to determine and predict river response in the study reach. The contract for physical modeling of the confluence has not been completed; however, a draft report dated May 1979 has been received.

The contracts for mathematical modeling of water and sediment transport have been with Colorado State University (CSU), Fort Collins, Colorado. The first mathematical modeling contract was for a one-dimensional model of pool 4 below Lake Pepin and the Chippewa River below Durand, Wisconsin. This contract was between Colorado State University and the U.S. Fish and Wildlife Service; the final report is dated October 1976. The model can be used to study the impacts of dredging and dredged material disposal alternatives on the hydraulic response and sedimentation patterns in the main channel.

The work group contracted with CSU to extend the one-dimensional model to include pools 5 through 8. This work was in progress as of October 1979. An additional contract was given to CSU to develop a two-dimensional mathematical water and sediment routing program and apply it to the lower part of pool 4. This model is intended to provide detailed information on dredging alternatives. A draft report on the model development and calibration (June 1979) has been proposed by CSU.

The Floodplain Management Work Group contracted with Owen Ayers and Associates, Inc., Eau Claire, Wisconsin, to evaluate the ability of a compound stream type of water and sediment routing model to predict the

changes in the water surface profiles during floods resulting from encroachment or loss of floodplain storage. This contract was completed; for more information the reader is directed to the Floodplain Management Work Group Appendix.

Dr. Ted Yang, North Central Division, Corps of Engineers, developed a strip version of the HEC-6 program, Scour and Deposition, for the DRWG to study two-dimensional bed changes. This program could be used to check the one- and two-dimensional analyses of lower pool 4 to be accomplished by CSU. As of October 1979, the program had been modified to the strip version but was not successfully duplicating measured bed changes.

B. Submerged Groins Physical Model

Channel constrictions are effective in establishing and maintaining depths sufficiently great to permit barge and other traffic during low-water periods. These constrictions are often groins projecting out from the banks. Research by the University of Minnesota was proposed to provide formulas for the relative distribution of flow and the relative depth of scour in constricted reaches. These data were required to improve the math modeling anticipated. The study also investigated the effectiveness of different groin field geometries.

The following conclusions were drawn by the contractor from the experimental data:

1. The basic concept of submerged groins in controlling depth of scour in the constricted region was verified. For low stages, the bed elevation was lowered in the constriction; for high stages and consequent submergence of the groin, the bed elevation approached the original bed elevation without the constriction.

2. The ratio of the discharge through the constriction to the total discharge was found to be primarily a function of the constriction geometry. Some evidence of roughness effects was observed, although the effects were not clearly defined. Therefore, the discharge ratio, for small changes in roughness, can be determined from:

$$\frac{Q_2}{Q_1} = \frac{1}{1 + \left(\frac{B_1}{B_2} - 1\right)\frac{D_3}{D_2}}$$

3. The dynamic equilibrium depth of scour, D_2 can be predicted as a first approximation with reasonable confidence with the equation based on the Brown-Einstein bed load formula:

$$\frac{D_2}{D_1} = \left(\frac{Q_2}{Q_1}\right)^{6/7} \left(\frac{B_1}{B_2}\right)^{\theta}$$

with θ = 0.714 for $\tau_o / \tau_1 << 1$.

By using the discharge ratio in item 2, the equation can be rewritten in terms of the groin submergence and scour depth as:

$$\frac{D_3}{D_1} = \frac{\frac{D_2}{D_1}\left[\left(\frac{D_2}{D_1}\right)^{-1.167}\left(\frac{B_1}{B_2}\right)^{0.833} - 1\right]}{\frac{B_1}{B_2} - 1}$$

4. The equilibrium scour depth ratio, D_2/D_1, was also found to be related to Shield's Shear Stress. Additional model studies and analysis are required to adequately define the relationship. Such studies should result in more complete basic knowledge of the scour phenomena.

5. The final selection of a groin configuration to be used depends on factors other than just the ability of attaining a prescribed scour depth in the constricted region. For example, consideration should be given to uniformity of scour depth across the entire width of the constriction as well as local scour around the tips of the groins. Of the groin types tested, it appeared that the downstream angled groin was the most efficient in this regard. Parallel wall constrictions were also efficient, but construction costs may be excessive in the prototype.

6. Selection of the groin type and longitudinal spacing of the groins also depends on conditions existing in the prototype, such as bends. These conditions may require additional model studies to assess the overall performance of submerged groins in such an application.

Symbols used are:

B_1	Upstream channel width
B_2	Constricted region channel width
D_1	Upstream channel depth
D_2	Constricted region channel depth
D_3	Depth over constriction

Q_1	Total discharge
Q_2	Discharge in constricted region
θ	Constant dependent on τ_c / τ_i.
	Mean upstream region shear stress
	Critical tractive stress of sediment

C. Chippewa and Mississippi River Confluence - Physical Model

To predict details of sediment movement, Colorado State University, under contract to the DRWG, developed a two-dimensional mathematical model for the confluence of the Chippewa and Mississippi Rivers. The physical model was considered necessary by the work group to provide data for the calibration of the mathematical model and verify the reliability of the math model. If time and funds permitted, the physical model was also to:

1. Compare the conditions before and after the construction of lock and dam 4 and determine the effect of the backwater on sediment movement.

2. Observe and measure the velocity distributions and the mixing process at key locations and correlate with the sediment movement characteristics.

3. Observe the filling process of dredge cuts.

4. Study the effect of various possible combinations of flow rates in the two rivers on the sediment movement, dredging requirements, and shifting of the thalweg.

5. Study the effectiveness of the alternative dredging practices that may be suggested by the mathematical modeling conducted by Colorado State University and/or by the physical modeling.

6. Study the effect of reduced sediment load in the Chippewa River on the sediment movement and dredging requirements in the Mississippi River.

7. Study the effect of new dikes or other structures on scour, aggradation, flow patterns, and sediment movement.

8. Study the effect of removing sediment in the Chippewa River using a sediment trap or a low dam.

9. Document the sediment movements under various test conditions by means of motion pictures. The film should be of professional quality, and a proof copy for possible inclusion in a film documentary must be made. Color 16mm film shall be used.

The physical model was constructed with a scale ratio of 1:200 horizontal and 1:40 vertical. The model was calibrated with field data gathered in fall 1977 and May 1978. The model bed was first molded to match that surveyed in fall 1977. The model was run with the recorded hydrograph, and the bed obtained was to match that surveyed in May 1978. After a few trial runs, a satisfactory final calibration run was obtained. The fall 1977 bed was used as initial condition for all runs.

After discussions with the Univeristy of Minnesota, Colorado State University, and the work group, the following runs were conducted:

1. Steady state runs with the following combinations of discharges:

a.	Mississippi River	19,000 ft^3/sec
	Chippewa River	30,000 ft^3/sec
b.	Mississippi River	7,000 ft^3/sec
	Chippewa River	7,000 ft^3/sec
c.	Mississippi River	50,000 ft^3/sec
	Chippewa River	30,000 ft^3/sec
d.	Mississippi River	50,000 ft^3/sec
	Chippewa River	7,000 ft^3/sec

In each of the steady state runs, the velocity of flow, water surface elevation, and the bed elevation were measured 4 times at 27 stations.

2. Dredge cut in the Mississippi River - constant discharges. The initial bed condition was prepared according to the 1977 survey data, except a dredge cut was made in the Mississippi River in accordance with the actual cut made in the field in May 1978. Constant rate of flows, 19,000 ft^3/sec in the Mississippi and 30,000 ft^3/sec in the Chippewa, and a constant rate of sediment feeding were maintained for this run. The resulting changes in the bed profile around the dredge cut area and the delta area were

measured intermittently six times during the run. The result clearly indicates that the dredge cut was filled by the moving sand waves. The detailed filling process of the dredge cut will be presented in the contractor's final report. Figure 6 summarizes the filling process and indicates, among other things, that the cut is completely filled at the model time of 14.6 hours (prototype time of 35.6 days).

3. Effect of sand removal at delta on the filling process of dredge cut at the Mississippi River - constant discharges. In addition to the dredge cut as described in the previous run, the same amount of sediment was also removed from the delta area. The dredge cut made in the delta was of the same area and depth as those made in the Mississippi River. An experimental procedure indentical to that of the previous run was used to study the influence of dredging at the delta on the sedimentation downstream. Again, the filling process was dominated by the moving sand waves. Figure 7 is a summary of the filling process at the Mississippi River cut. The rate of filling for this run is considerably less than that of the previous run. It took 24.2 hours model time or 60 days prototype time to deposit the same amount of sand that was removed from the cut.

4. Response of the river to an extreme 1-year hydrograph. The model was tested with the combination of a 1943 (very wet year) hydrograph for the Chippewa River and a 1934 (dry year) hydrograph for the Mississippi River, starting with the bed profile of 1977. Only the portion of the hydrographs between March 27 and July 15 was used in the test. The test was stopped three times during the run, and the bed profile was surveyed.

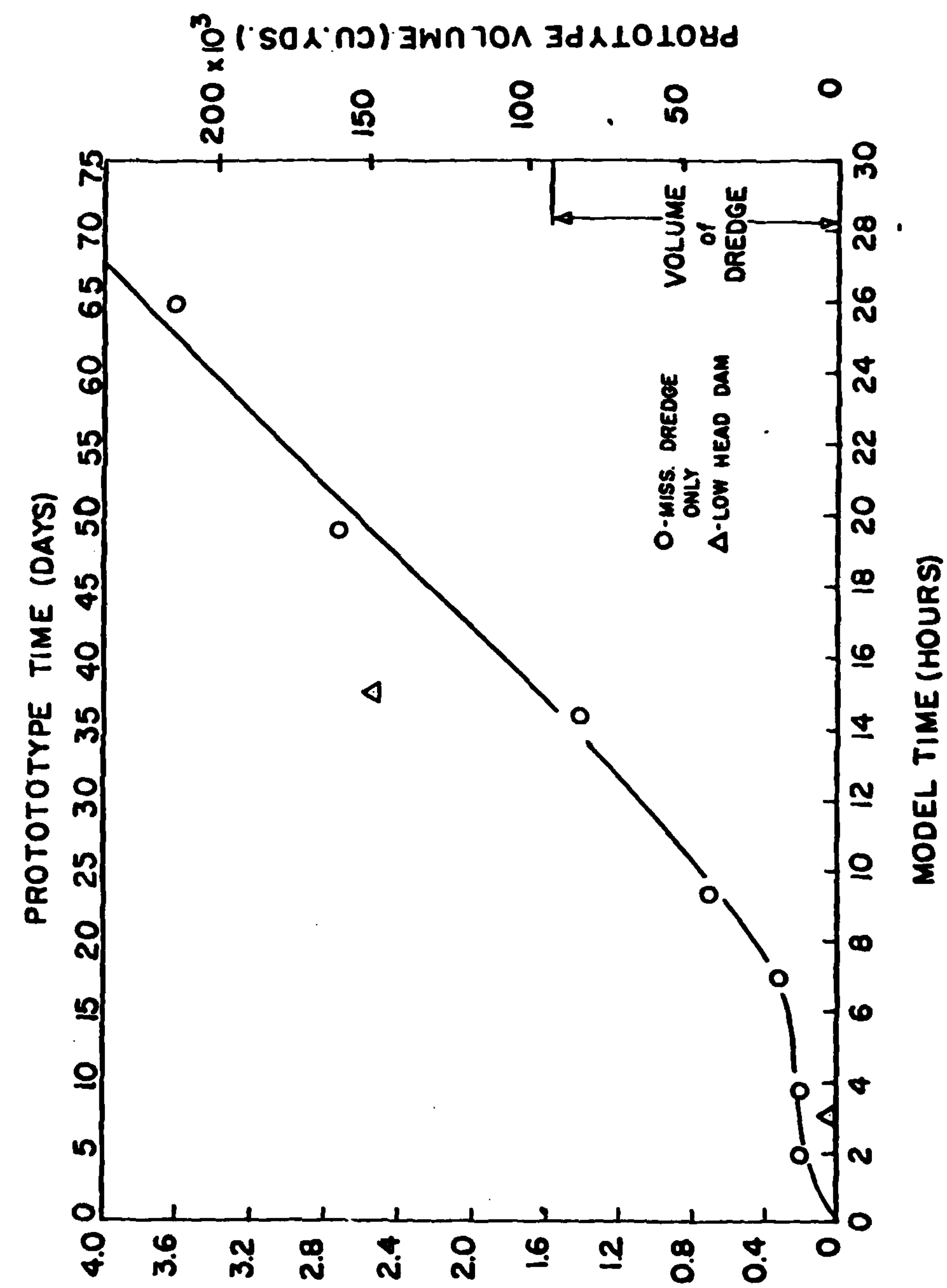


Figure 6 Rate of Deposition within the Dredged Area,
No Sediment Removed at Delta
(after Song, Johnson, Long, and Selby, 1979)

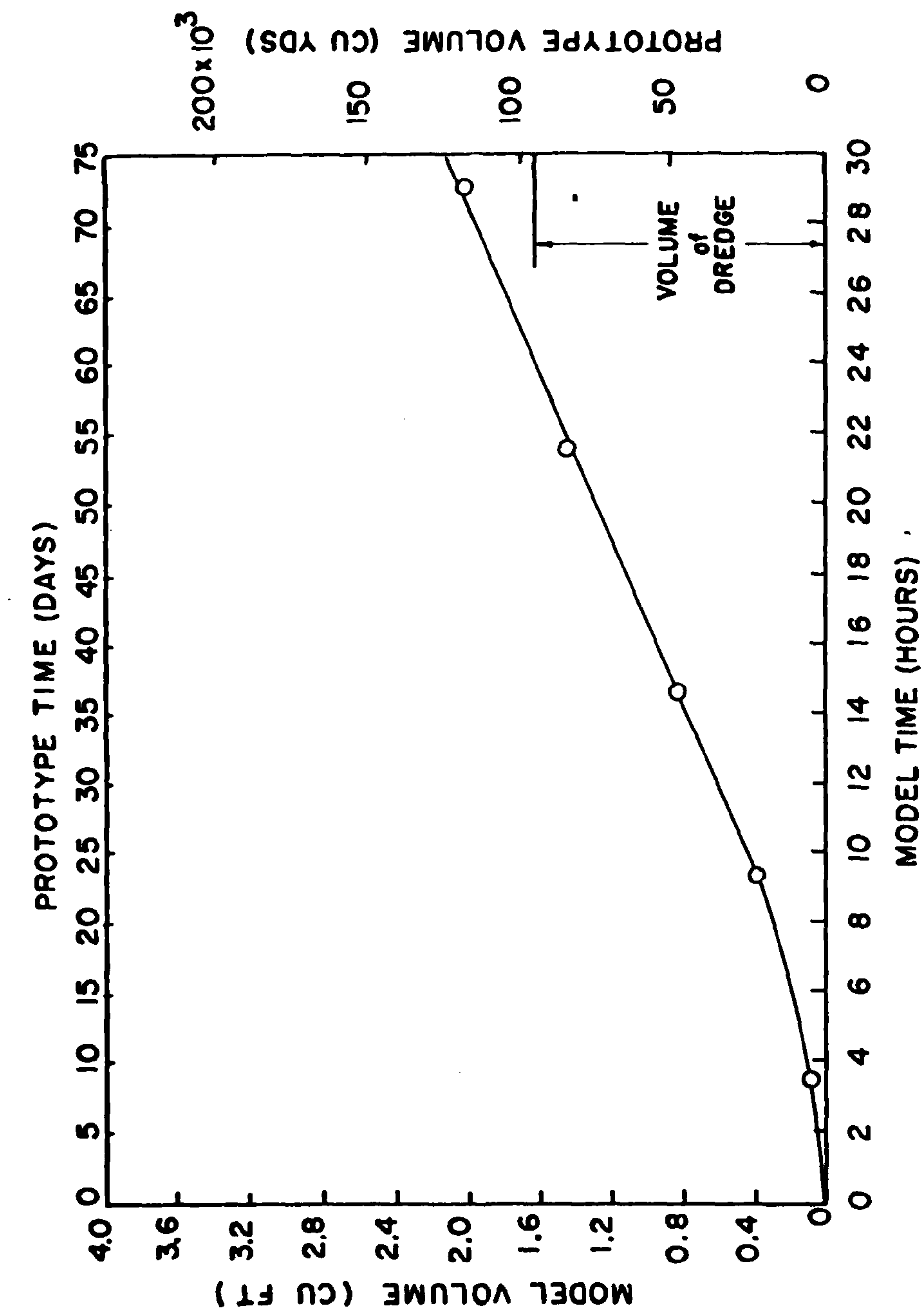


Figure 7 Rate of Deposition within the Dredged Area,
Some Sediment Removed From Delta
(after Song, Johnson, Long, and Selby, 1979)

The major findings of this experimenta` .n are listed below:

a. The bed profile in the Chippewa River portion of the model remained relatively unchanged during the entire period.

b. The bed configuration changed substantially in the delta area. The large discharge from the Chippewa River created a well-defined channel in the delta and deposited sediment along both sides of the channel.

c. Most of the sediment carried into the Mississippi River during this period was deposited in a stretch of the river between the mouth of the Chippewa River and the upstream end of Drury Island. Only at approximately the beginning of May did the sand wave begin to move downstream.

d. The mean bed elevation did not change appreciably at the downstream end.

5. Effect of low-head dam at the downstream end of Chippewa River. A low-head dam, top elevation 665.0, was placed across the downstream end of the Chippewa River. Some riprap was placed in an area extending 200 feet downstream from the low-head dam to prevent erosion of the dam foundation. Except for these changes, the initial bed profile was the same as that used for the previous run. Steady state flows of 30,000 ft^3/sec in the Chippewa River and 19,000 ft^3/sec in the Mississippi River were used.

Concentration of a large amount of energy immediately downstream of the dam quickly generated a large scour hole downstream of the riprapped area. The material scoured was deposited immediately downstream of the scour hole. Unfortunately, the scour hole

had reached the concrete floor of the model and the test after this time would not accurately represent the would-be prototype condition. According to this model, the scoured material would move downstream in a sand wave and eventually arrive at the dredged area. The rate of filling at the dredged area may temporarily increase when this sand wave arrives but will soon decrease because of a lack of sediment supply from the Chippewa River. The sediment deposition within the dredged area was measured only twice and the data are shown on Figure 6 as triangles.

The size of the scour hole is surprisingly large considering that the dam was only about 8 feet high. It is not certain to what the degree the scale effect influenced the experimental result.

The University of Minnesota reached the following conclusions from its work under the original contract:

A physical model of the confluence of the Chippewa and Mississippi Rivers was constructed, calibrated, and tested. A modest amount of geometrical distortion was tolerated. Because the major objective of the model study required the simulation of the bed load movement, the Froude number was also distorted by a factor of 1.85 to maintain the stream power similarity. In this way, the model was able to reproduce fairly accurately the bed profile changes in the field from September 1977 to May 1978. Data obtained from a tilting flume experiment also

indicated that the combination of the geometrical and Froude distortions produced the correct amount of sediment transport rate. That is, the sediment transport rate measured in the model could be scaled up and matched to the field data taken in the Chippewa River. The calibrated model was then tested under several hypothetical conditions. The results of these tests are presented in this report. Close examination of these data leads to the following conclusions:

1. A distorted physical model of a river can be used to simulate the bed load transport of the river quite accurately, provided that the dimensionless stream power of the model is made equal to that of the prototype. The dynamic similarity of the flow based on the Froude law can also be achieved if the overall roughness of the model is properly adjusted.

2. The overall roughness of the model was not completely adjusted so the Froude similarity was not achieved simultaneously with the stream power similarity. To do so would require greater roughness in the model.

3. The amount of sediment existing in the delta area before a spring flood, together with the magnitude of the spring flood, particularly that of the Chippewa River, is the determining factor for the rate of sediment deposition near Drury Island. Depending on the duration and the magnitude of the flood, the sediment wave may not reach Drury Island until after one flood has passed.

4. Removal of sand from the delta area greatly reduces the rate of sediment deposition near Drury Island. For a reason that is not fully understood at this time, the amount of reduction in the sediment deposition in the dredged area exceeded the amount of sand removed from the delta area.

5. During a period of relatively low flow in the Mississippi River but hgh flow in the Chippewa River, scouring of the delta will occur. Conversely, deposition at the delta should occur when the flow in the Chippewa is not too high but the stage in the Mississippi River is maintained for navigation.

6. A low-head dam in the Chippewa River will probably cause some scouring of the delta and increase deposition at the dredged area shortly after its construction. This effect should diminish with time.

Some interesting but unanswered questions remained after the initial contract:

1. At least for the condition tested the reduction of sediment deposition in the dredging area exceeded the amount of sediment initially removed from the delta area. The excess sediment could be transported farther downstream without depositing in the dredged area or deposited upstream of the dredged area and move to the dredged area later. The benefit of sand removal at the delta would be great if the former is the case. This subject deserves further investigation.

2. Because the amount of sediment in the delta and the magnitude of the flow from the Chippewa River are major factors affecting the deposition in the dredged area, the dredging requirement might be predicted from the condition at the delta and the flow in the Chippewa River. The possibility of developing a simple forecasting model using additional data from physical model testing and mathematical modeling would be worth pursuing.

3. A low-head dam built to capture the sediment in the Chippewa River may create local scouring and deposition shortly after its construction. More detailed study is needed. Also, the long-term effect of starving the Mississippi River should be investigated. Because the Mississippi River requires some sediment to maintain equilibrium, it may be best to partially retain the sediment in the Chippewa River and continue to feed the Mississippi River at a reduced rate.

4. The possibility of using wing dams or submerged groins to reduce sediment deposition may be worth studying.

To help answer these and other questions, the Corps of Engineers and the University of Minnesota entered into a supplemental agreement in October 1979 for additional runs of the physical model. These runs will be used to evaluate dredging modifications and alternatives. The work is to be completed in late summer 1980.

D. One-Dimensional Mathematical Model of Lower Pool 4

The U.S. Fish and Wildlife Service contracted with Colorado State University to develop a one-dimensional mathematical model of lower pool 4 of the Upper Mississippi River. The model could be used to study the general impacts on the river of different operating schemes for the locks and dams, the effects of the pools on the behavior and form of the tributary rivers, the impact of changes in the delivery of sediment and water to the study reach on the morphology of the river and adjacent lands, and the impacts of dredging and dredged material disposal on the hydraulic response and sedimentation patterns in the main channel. The computer program uses a linear-implicit method to simultaneously solve finite-difference approximations of the partial differential equations for water continuity, flow momentum, and sediment continuity. Sediment discharge is related to the flow and channel characteristics by a sediment transport function based on Toffaleti's method.

To simulate the geomorphic changes in the Chippewa River and the sediment transport from the Chippewa to the Mississippi River, the model was calibrated to reproduce the filling process of the 1965 dredge cut made in the Chippewa River near the mouth. The calibration was successful; however, because the quantitative model calibration only covered the lower Chippewa River near the mouth, the geomorphology of the rest of the modeled reach of the Chippewa River could only be studied qualitatively.

Future geomorphic changes that may occur in pool 4 in the Upper Mississippi and lower Chippewa Rivers as a result of present and anticipated future developments were assessed. The responses expected are:

1. If the pools are operated in the present-day manner for the next 10 years and if the sediment load to the study reach remains essentially unchanged, the riverbed in pool 4 would aggrade approximately 0.7 foot overall. The lower one-third of the Chippewa River would have aggraded 0.1 foot.

2. Under the present-day manner of operation and with normal sediment loads, the natural levees along the riverbanks and on the islands would grow on the average approximately 0.5 foot in height in the next 10 years.

3. Under the present-day manner of operation, on the average, approximately 0.5 inch of silts and clays would be deposited on the unprotected floodplains along the study reaches in the next 10 years.

4. The geomorphic changes caused by operating with the pool 1 foot above normal pool for 10 years do not differ significantly from operation at normal pool level. Increasing the pool level causes aggrading reaches to aggrade more and degrading reaches to degrade less.

5. Holding the pool 1 foot above normal for 10 years would increase deposits on the natural levees and on the floodplains, but these increases are not significant.

6. If the sediment inflow to Durand in the Chippewa River were reduced by 50 percent, the river would degrade in the Chippewa River below Durand, but there would be little effect on riverbed elevations in pool 4 in the next 10 years.

7. A larger flood would produce more severe sedimentation problems in pool 4 than a smaller flood.

8. A 1-foot-deep dredge cut near Reads Landing would not have survived after the passing of a 5-year annual hydrograph but may last through a 2-year annual hydrograph.

9. A dredge cut may serve as a sediment trap to reduce the sedimentation problem downriver. A large dredge cut made in the lower Chippewa River would reduce the deposition rate in the Mississippi River below the confluence.

The principal limitation of this mathematical model is its assumption of one-dimensional flow. Only the general pattern of the river geomorphology can be considered. To perform a detailed study, either a two-dimensional model should be developed or a modification of the present model can be made by using a compound stream approach (Dass, 1975). Since no width predictor was included in the mathematical model, the changes in channel width with time should be accepted as known quantity or should be evaluated using qualitative geomorphic concepts. To overcome the one-dimensional limitation, Colorado State University was contracted to develop a two-dimensional model.

E. Two-Dimensional Mathematical Model of Lower Pool 4

Colorado State University was awarded a contract to develop a two-dimensional mathematical model of lower pool 4 to be able to investigate (in greater detail than the one-dimensional model dredging requirements) stabilities of dredge cuts, effects of modifications of the existing system to reduce dredging requirements, and sediment transport into the backwater areas. A review of the literature on mathematical modeling revealed that all the available mathematical models were one-dimensional. Thus, for the first time in this Nation, a two-dimensional mathematical model is being developed to predict the response of a major review to engineering construction and operation. Because this method is untried, the DRWG decided to take extra precautions to verify its validity and accuracy. One of the main purposes of the physical model of the confluence of lower pool 4 was to verify the two-dimensional mathematical model. The DRWG also contracted for the development of the strip version of the program HEC-6 to provide a completely independent model to make a detailed verification of the assumptions and computed results of the CSU two-dimensional model.

The two-dimensional model contract consisted of two parts. The first part included development of the two-dimensional mathematical model, construction of the model of lower pool 4 of the Upper Mississippi River and Lower Chippewa River, and calibration of the model to reproduce the physical model and prototype characteristics. The draft report on this

part of the contract is dated June 1979. The second part of the contract included applications of the developed two-dimensional model to assess impacts of various navigation channel maintenance and development works. This portion had not been completed as of July 1979.

The model is based on the conservation of mass by satisfying the water continuity equation and sediment continuity equation and is based on the conservation of momentum by satisfying the momentum equations along two perpendicular horizontal directions. The flow properties in the vertical direction are averaged. These four governing equations are solved by numerical methods using a digital computer. A sequential water and sediment routing procedure is used for solving the governing equations by solving the hydrodynamic equations for water routing and solving the sediment continuity equation for sediment routing. The hydrodynamic equations are solved by using an alternating-direction implicit method, based on that used by Leendertse (1967). The calculated hydraulic variables are substituted into sediment transport functions to determine sediment transport rates. The sediment function gives bed material transport based on a power function of the mean velocity. These rates are then used in the sediment continuity equation expressed in a finite-difference explicit form to determine the change in the bed elevations.

The effective shear stresses in the hydrodynamic equations are neglected in the model. These are the shear stresses that are generated between adjacent flows of water with different velocities or direction. At the

present time, there is no consensus among researchers on the importance, effect, and need for these terms. The effective shear stresses appear to have an effect on circulating flows. The contractor concluded that more research is needed before two-dimensional modeling can be effectively applied to more complex circulating flows that may occur at rapid expansions and contractions.

The developed two-dimensional water and sediment routing model was applied to model pool 4 in the Upper Mississippi River and in the lower Chippewa River near the confluence. This mathematical model was calibrated using the physical model results collected by the University of Minnesota. The data collected in steady state runs of the physical model were used for calibration. The first run had prototype discharges of 30,000 ft^3/sec (high flow) in the Chippewa River and 19,000 ft^3/sec (intermediate flow) in the Mississippi River. The second and third runs considered the same flow conditions as the first run, with the addition of a dredge cut(s) in the Mississippi River.

The first run made with the mathematical model was carried out to simulate the two-dimensional flow patterns in the study reach under the following steady flow conditions: water discharge in the Mississippi River immediately downstream of Lake Pepin, 19,000 ft^3/sec (intermediate flow); water discharge in the Chippewa River upstream of its confluence with the Mississippi River, 30,000 ft^3/sec (high flow). The corresponding physical model discharges are 0.69 ft^3/sec and 1.10 ft^3/sec, respectively.

Figure 8 shows the results of the calibration run, depicting the overall agreement between calculated and measured values of water discharge (discharge vectors are shown at the scale of 0.5 ft^3/sec/ft per foot of physical model dimensions). The agreement between predicted and measured depths and discharge distributions is good. This indicates that the water routing component of the developed two-dimensional mathematical model can adequately simulate the physical model. Calibration of the sediment routing component of the mathematical model was performed in the next two runs.

The second run on the mathematical model was carried out to simulate filling of a dredge cut immediately upstream of Drury Island. On the basis of the results of the physical model study conducted by the University of Minnesota, it was found that Yang's Unit Stream Power Relation was applicable to determine the sediment transport rate in the physical model. The transport equations obtained from Yang's relation were modified at some grid points because of the approximations to the natural river contour using rectangular grids and neglecting a small side channel upstream of Drury Island in the mathematical model.

The agreement between the calculated and measured sediment deposition in the dredge cut was quite good as shown in Figure 9. However, some differences between the calculated and measured bed profiles exist. This indicated that the initial bed elevations, flow distributions, celerities of bed wave movement, and sediment transport rates in the mathematical model are somewhat different from those in the physical model. Also, the approximations to the natural river contour used in the mathematical model affect the bed wave movement along the riverbanks. The riverbank geometry could be modeled more closely in the mathematical model by use of

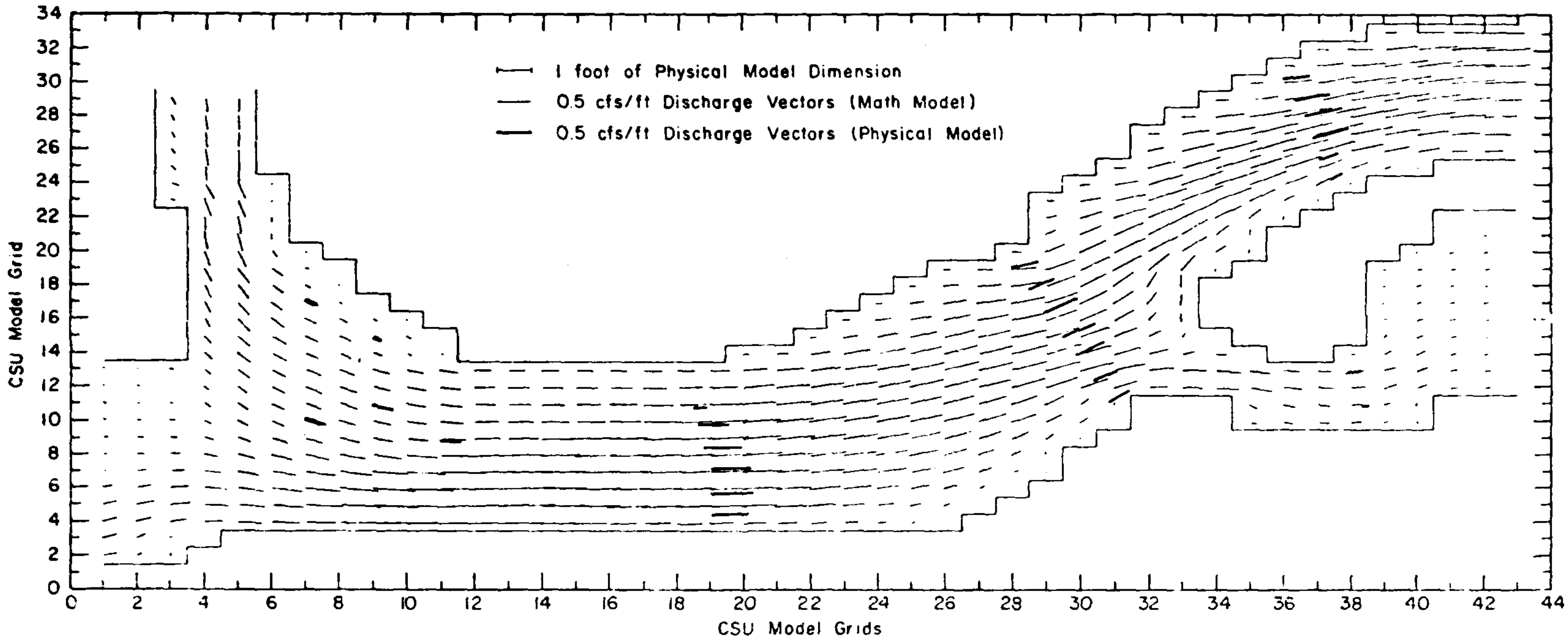


Figure 8 Comparison Between the Computed Discharges (Mathematical Model)
and the Measured Discharges (Physical Model)
(after Simons, Chen, and Ponce, 1979)

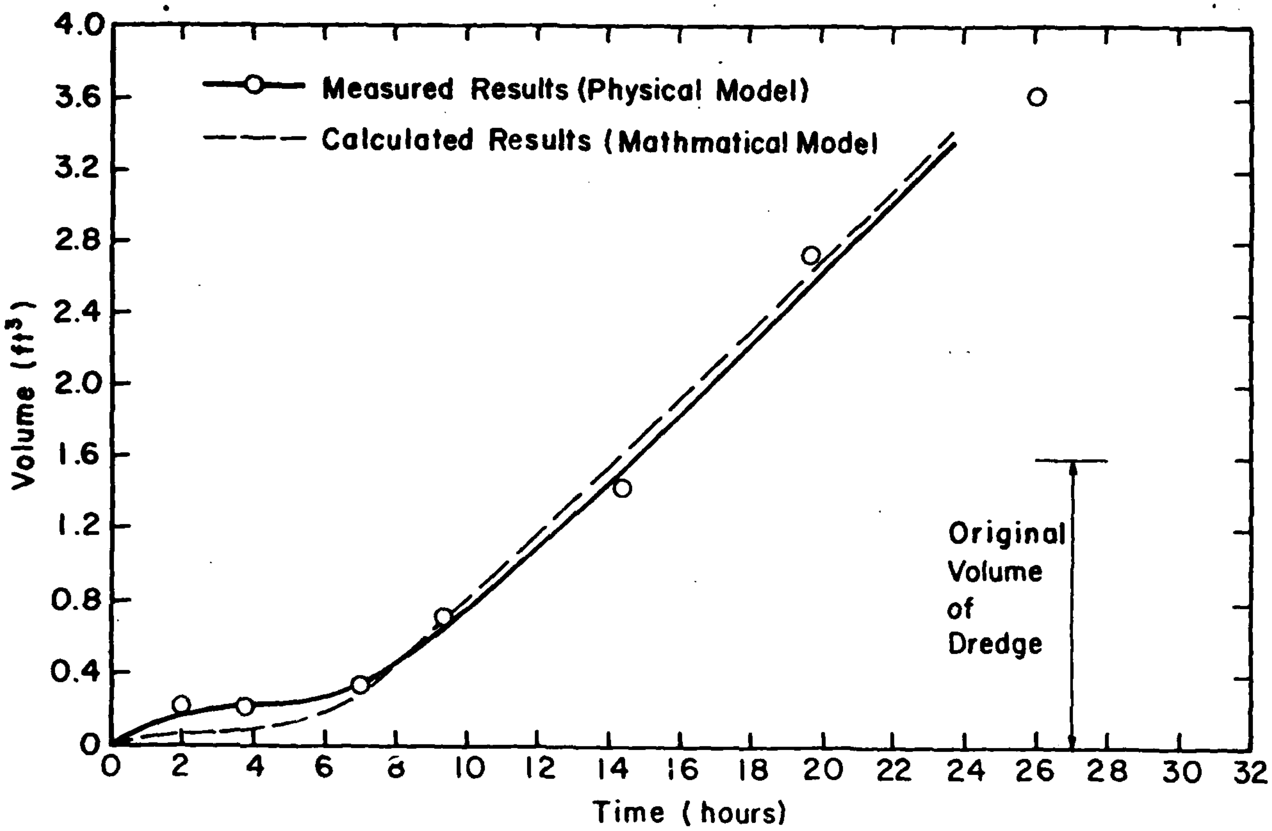


Figure 9 Comparison Between the Calculated and Measured Amount of Sediment Deposited in the Dredge Cut (One Dredge Cut)
(after Simons, Chen, and Ponce, 1979)

finite elements rather than finite differences. The finite element method was tried by the contractor, but the analysis was found to use far too much computer time. However, developments in numerical analysis and increases in computer capability may make the finite element method practical in the future.

The third run was carried out to simulate the effects of a dredge cut made at the confluence on the filling of the downstream dredge cut located immediately above Drury Island. Again, there were some differences between calculated and measured bed profiles. The contractor concluded that these differences were mainly caused by the rectangular grid approximations of the riverbanks in the mathematical model and the differences in flow distribution and in sediment transport rates. Figure 10 shows the filling of the downstream dredge cut. Comparison of Figure 9 and Figure 10 indicates that the dredge cut made at the confluence slowed down the filling of the downstream dredge cut.

The filling rate in dredge cut 1, calculated in the mathematical model with two dredge cuts, was faster than that measured in the physical model as shown in Figure 10. The possible reasons suggested by the contractor are:

1. The initial bed elevations between the locations of the two dredge cuts in the physical model for the second run could be different from that for the third run.

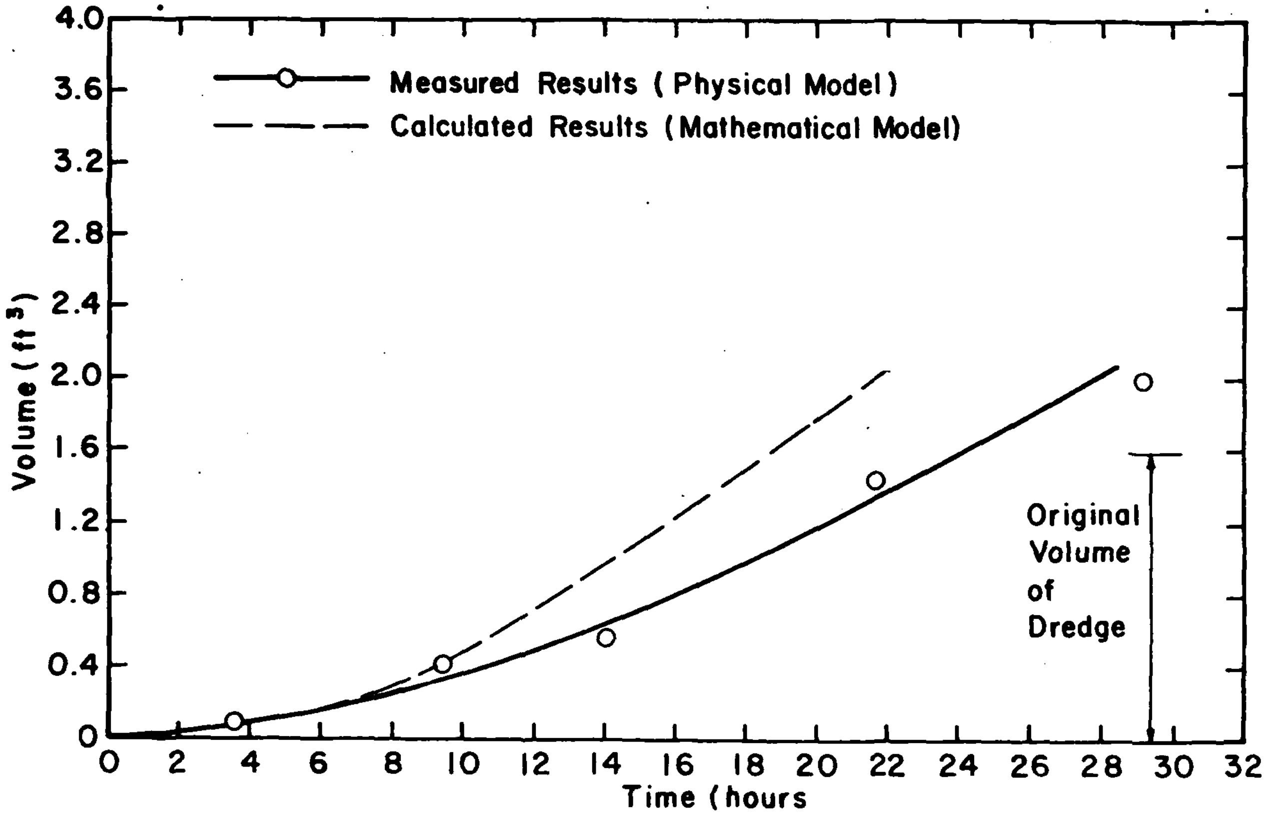


Figure 10 Comparison Between the Calculated and Measured Amount of Sediment Deposited in Dredge Cut (Two Dredge Cuts)
(after Simons, Chen, and Ponce, 1979)

2. The initial bed elevations at some computational grids in the mathematical model when not measured were based on linear interpolations of the measured bed elevation at nearby locations - this could affect the calculated results.

3. The water flow patterns and sediment transport rates in the mathematical and physical models differ and could affect the calculated results.

The calculated results in the mathematical model and the measured results in the physical model reasonably agree. This verifies the applicability of the two-dimensional mathematical model developed here to study qualitatively the water- and sediment-related problems in a river system. The model also shows promise for the quantitative study of water and sediment movement. However, on the basis of the data presented in the June 1979 draft report, the DRWG concluded that the two-dimensional mathematical model needs further calibration and verification before it can be used to predict detailed responses of river systems.

F. One-Dimensional Mathematical Model of Pools 5 through 8

This model is to be an extension of the model developed by Colorado State University for pool 4. The methods used by the program and the anticipated uses of the model are similar to those discussed for the one-dimensional model for pool 4. The work on this contract is scheduled for completion on 31 December 1979. No preliminary results are available.

The contractor will quantitatively evaluate the sediment movement through the system. Sediment accumulation or scour will be defined for each pool. Years of low, medium, and high flows will be examined, and normal lock and dam operation will be assumed. The computer model will be used to assess:

a. The response of major tributaries to main channel development.

b. The effects of the present locks and dams and different operating schemes for these dams on the geomorphology of pools 5 through 8 and adjacent floodplains.

c. The effects of river channel dikes and revetments on the banks and riverbed.

d. The impact of dredging on the hydraulic response and sedimentation patterns in the study area.

e. The feasibility of riverine disposal in pools 5 through 8.

f. The identification of possible alternative methods of maintaining a 9-foot navigation channel at specific sites and identification of possible actions that might be taken to reduce dredging at specific sites.

As part of the contract, the computer program and calibrated model and directions for use will be provided to the Government.

G. Compound Stream Model of Pool 4

This contract was between the Floodplain Management Work Group and Owen Ayers and Associates, Inc., Eau Claire, Wisconsin. The contract has been completed. A discussion of this model is given in the Floodplain Management Work Group Appendix. The applicability of this model for use by the DRWG to develop alternatives and modifications to the dredging program to minimize dredging quantities is discussed here.

The compound stream model is a mixture of one- and two-dimensional models. In this model, channel cross sections are divided into strips, usually right and left overbanks and the main channel. One-dimensional partial differential equations representing the conservation of mass for sediment and the conservation of mass and momentum for sediment-laden water are used. The model treats the flow in the strips separately and accounts for the interaction of water and sediment flows between the strips.

Since almost all bed material movement is in the river channel, with very little in the overbanks, a three-strip, compound stream model probably offers small advantage over a one-dimensional model for studying channel bed changes. However, the Floodplain Management Work Group preferred the compound stream model for evaluating the effects on flood stages of dredged material disposal sites in the overbank areas. Flow into and out of the overbank areas is considered in the Colorado State University one-dimensional model, but the analysis is not as rigorous as in the compound stream model.

H. Strip Version of HEC-6

Dr. C. Ted Yang, formerly with the Corps, North Central Division, modified the HEC-6, Scour and Deposition in Rivers and Reservoirs, for the DRWC, to solve two-dimensional problems. The purpose of developing this model was to check the one- and two-dimensional analyses of Colorado State University. Unfortunately, Dr. Yang left the Corps before the modification was completed. Work was carried on after Dr. Yang's departure by Albert Molines, North Central Division, and Tony Thomas, Waterways Experiment Station. As of July 1979, the program had been modified and was running, but could not be successfully calibrated to duplicate measured bed changes.

The HEC-6 program is steady-state, and one-dimensional, unlike the unsteady-state, one- and two-dimensional models of Colorado State University and the compound stream model. Steady-state programs, such as HEC-6 and HEC-2, assume the discharge does not change in direction or magnitude during each time interval. For the slowly rising and falling Mississippi River, the use of a steady-state model is probably acceptable for one-dimensional analysis. For two-dimensional analysis, an unsteady-state program may be necessary to successfully model detail changes in magnitude and direction of the flow of water and sediment.

The advantage of HEC-6 is that the sediment transport part of the program is the most comprehensive available in any model. It has the option of using different sediment transport equations. It also includes

the effects of armoring of the bed caused by erosion of graded bed material. A more complete description of the program is contained in the Users Manual, published by the U.S. Army Corps of Engineers Hydrologic Engineering Center in March 1976.

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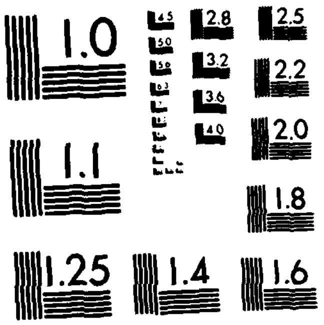

MICROCOPY RESOLUTION TEST CHART
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APPENDIX A

ETL 1110-2-225
ENGINEERING AND DESIGN
CHANNEL WIDTHS FOR NAVIGATION IN BENDS

APPENDIX A

DEPARTMENT OF THE ARMY
Office of the Chief of Engineers
Washington, D. C. 20314

ETL 1110-2-225

DAEN-CWE-H

Engineer Technical
Letter No. 1110-2-225

1 July 1977

Engineering and Design
CHANNEL WIDTHS FOR NAVIGATION IN BENDS

1. Purpose. This ETL describes a study authorized by the Office of the Chief of Engineers, dated 14 November 1974, to obtain better information on factors affecting channel widths for navigation in bends. It was undertaken by the U.S. Army Engineer Waterways Experiment Station utilizing small scale models in which conditions could be varied and controlled.

2. Applicability. This letter applies to all field operating agencies having Civil Works responsibilities.

3. Design Factors. Development of inland waterways for navigation must be based on the characteristics of the waterway and the requirements of the type of traffic for which it is designed. Most inland waterways utilize all or part of an existing stream which consists generally of alternating bends and straight reaches. Towboats and tows occupy greater channel widths when making a turn or negotiating bends than when moving in a relatively straight line. The width of channel occupied depends on many factors which have to be considered in the design of the navigation channels. Some of these factors include rate and amount of change in direction required in a given bend, current velocities and alignment of currents, length and width of towboat and tow, and speed and maneuverability of the tow. The specific objective of the study is to develop parameters which can be used by the design engineer in determining the channel widths required under various conditions.

4. Principles Involved. If the size of the tow, radius of the bend, and orientation assumed by the towboat and tow in negotiating the bend are known, the width of channel required can be determined. Since the first two factors are readily available, the only unknown is the orientation of the towboat. This can best be defined as the deflection angle α formed by the alignment of the boat and a chord on the curve of the bend equal to the length of the towboat and tow (Figure 1). If the deflection angle is known for a particular condition, a reasonably accurate channel width can be determined for that condition from one of the following equations:

a. $CW_1 = (\sin\alpha_d \times L_1) + W_1 + 2C$

b. $CW_2 = (\sin\alpha_u \times L_1) + W_1 + (\sin\alpha_d \times L_2) + W_2 + 2C + C_t$

where: CW_1 = channel width required for one-way traffic, ft

CW_2 = channel width required for two-way traffic, ft

α_d = maximum deflection angle of a downbound tow, deg

α_u = maximum deflection angle of an upbound tow, deg

L = length of tow, ft

W = width of tow, ft

C = clearance required between tow and channel limit for safe navigation, ft

C_t = minimum clearance required between passing tows for safe two-way navigation, ft

The orientation (deflection angle) assumed by the tow under various conditions has not previously been clearly established and is the most difficult parameter to determine. Model studies are being used to determine the deflection angle which can be substituted in the equations to obtain channel widths.

5. The Channel Models. The channels being modeled for these studies are designed to provide the variables associated with channel configuration such as curvature of bend and current distribution, alignment, and velocity. In order to provide for some of these variables, the model reproduces a series of typical bends of uniform curvature and different radii with straight reaches between alternate bends. The models are molded in compacted sand to typical channel cross sections and can be readily remolded to provide for various curvatures of bend and different model scales. The models are adjusted by modifying the channel cross section to provide realistic current alignment and velocity distribution.

6. The Tow Models. The tows used in these tests are remote controlled and variable in length and width as required for the tests. All tows were loaded to a draft of 8 ft based on project depth of 9 ft. Results shown are based on an analysis of several runs with the speed of the tow maintained constant during each run. The speed of the tow is set at the minimum required to navigate against the current and provide adequate rudder control. Results of downbound tows are based on negotiating the bends without flanking. Tests are conducted with slack water (no flow) and with flows producing average velocities of about 3 and 6 ft/sec (Figures 2 and 3).

7. Test Conditions. Sufficient data have been collected to indicate the variations in the deflection angle for 90-deg bends as affected by bends with radii from 1500 to 3000 ft, tow sizes from 35 to 70 ft wide by 685 ft long to 105 ft wide by 600 ft long, and current velocities

between 0 and 6 ft/sec for downbound tows without flanking and for upbound tows.

8. Test Results. The effects of tow size and makeup on channel width required are illustrated in Figure 4. This illustration indicates that a shorter and wider tow will usually require less channel width in bends than a longer and narrower tow of the same tonnage. For instance, the 80- by 600-ft tow requires 10 ft less channel width than the 70- by 685-ft tow. As the radius of the bend decreases, the deflection angle increases; therefore, the required channel width increases (Figure 5). It should be noted that tow size has a somewhat lesser effect on the variation in deflection angle for upbound tows or tows moving in slack water than for downbound tows. It should also be noted that the deflection angle for tows moving in slack water is somewhat greater than for upbound tows moving in 3-ft/sec current. Given a radius of curvature and normal velocity distribution, the deflection angle can be obtained from Figure 5 and the required channel width computed for average conditions using equation a or b for the tow sizes indicated.

9. Environmental Constraints. River currents in natural streams are affected by factors other than the geometry of the immediate bendway; therefore, the data presented should not be applied indiscriminately. The alignment of the channel upstream and the existence of hard points or other anomalies can affect normal current patterns and must be considered. In the absence of anomalies, currents generally follow the thalweg around a bank during low water when channel widths and depths are minimum. This will be the limiting condition in most cases and the fact that currents follow a somewhat different alignment during high water should not be significant.

10. Carrier Constraints. The data presented are based on a towboat with the minimum power to adequately navigate under the conditions specified. Tows with greater power for the load can develop more rudder control and require less channel width than indicated. Also, tows that have greater maneuverability because of independent operation of their screws, specially designed rudders, or auxiliary steering devices will require less channel width than indicated by the results of the tests. Conversely, tows with insufficient power to properly handle the load would tend to slip sideways in making the turn and would require a greater channel width than indicated.

11. Conclusions. The studies completed to date indicate the following:

a. The channel width required in bends is greater than that in straight reaches for the same size tow. The width required will depend on the orientation of the tow with respect to the alignment of the channel while negotiating the bend.

b. The orientation of the tow in a bend can best be defined by the deflection angle, which is influenced by the curvature of the bend, size

of the tow, alignment and velocity of currents, and power and maneuverability of the towboat with respect to the load.

c. The channel width required for short radius bends (1000 to 3000 ft) can be approximated from the preliminary results contained in Figure 5 and the equations in paragraph 4.

d. Channel widths and current direction and velocities in a stream will vary with stage and discharge and should be considered in determining the most critical conditions.

e. Shorter and wider tows usually require less channel width in bends than longer and narrower tows carrying the same load, particularly in short radius bends.

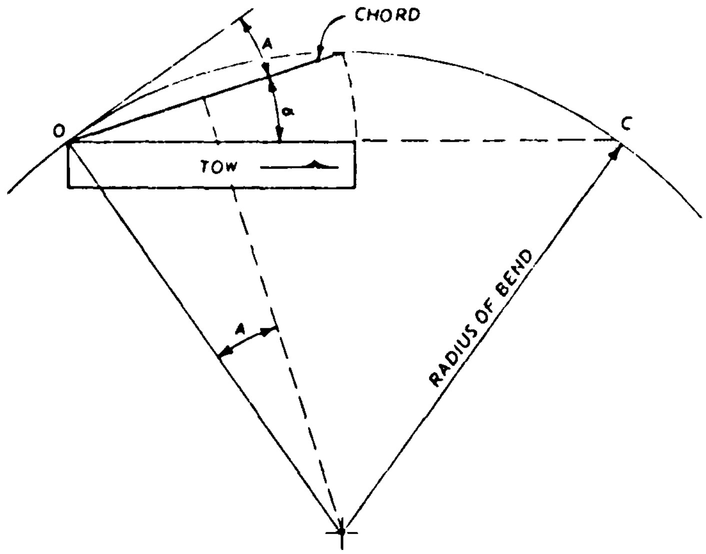
f. In streams carrying little or no sediment, it may be more economical to increase the width of channel than to increase the radius of the bend. In streams carrying a heavy sediment load, an increase in the channel width cannot be maintained without the addition of properly designed construction of training structures.

FOR THE CHIEF OF ENGINEERS:

Homer B. Willis

1 Incl
Figures 1-5

HOMER B. WILLIS
Chief, Engineering Division
Directorate of Civil Works



LEGEND

CHORD = LENGTH OF TOW
A = CHORD ANGLE
α = DEFLECTION ANGLE
O – C CHORD BASED ON TOW ALIGNMENT MOVING THROUGH THE BENDWAY

DESCRIPTION OF THE DEFLECTION ANGLE α

Figure 1

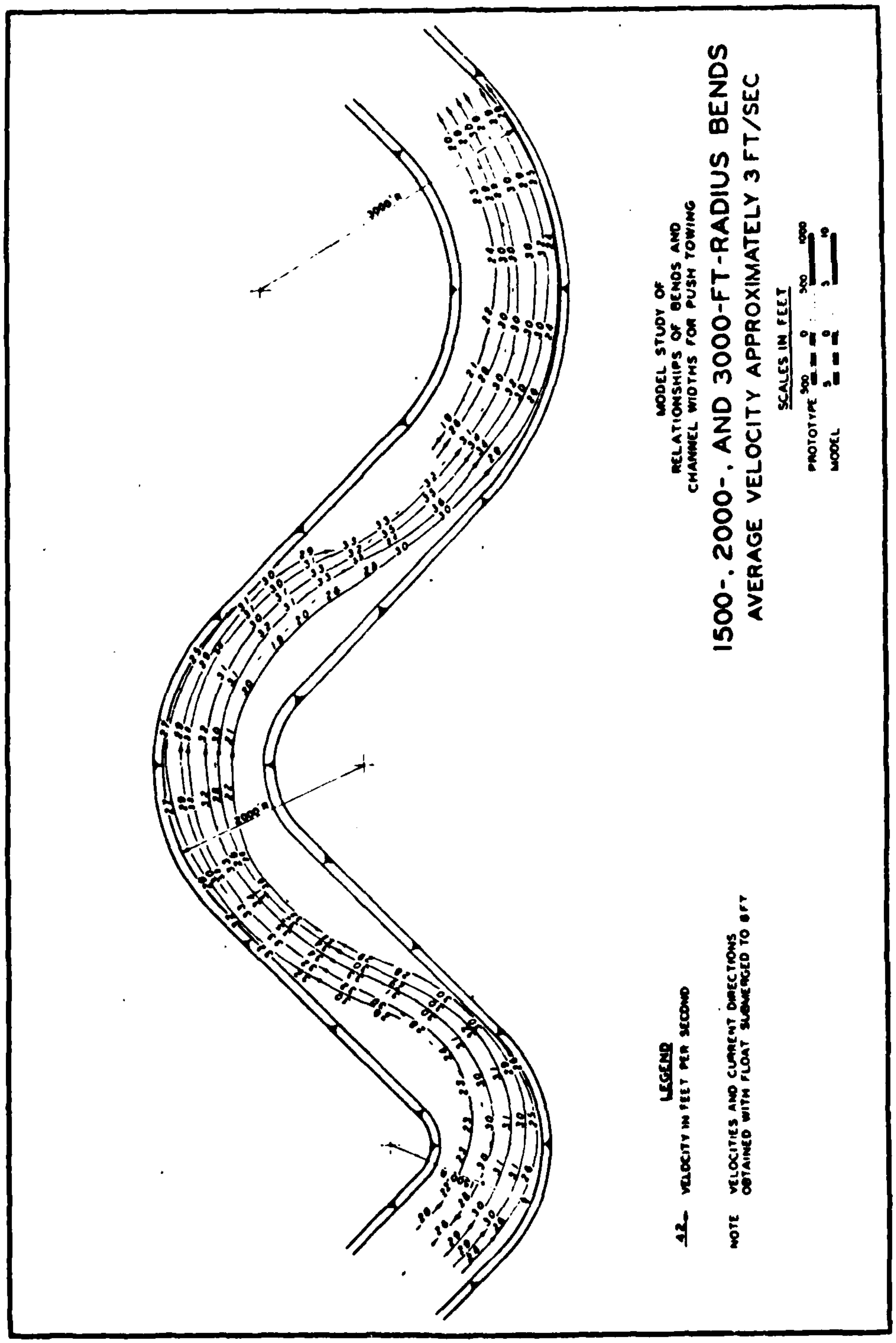

MODEL STUDY OF
RELATIONSHIPS OF BENDS AND
CHANNEL WIDTHS FOR PUSH TOWING
1500-, 2000-, AND 3000-FT-RADIUS BENDS
AVERAGE VELOCITY APPROXIMATELY 3 FT/SEC
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
VELOCITY IN FEET PER SECOND
NOTE VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO 8 FT

Figure 2

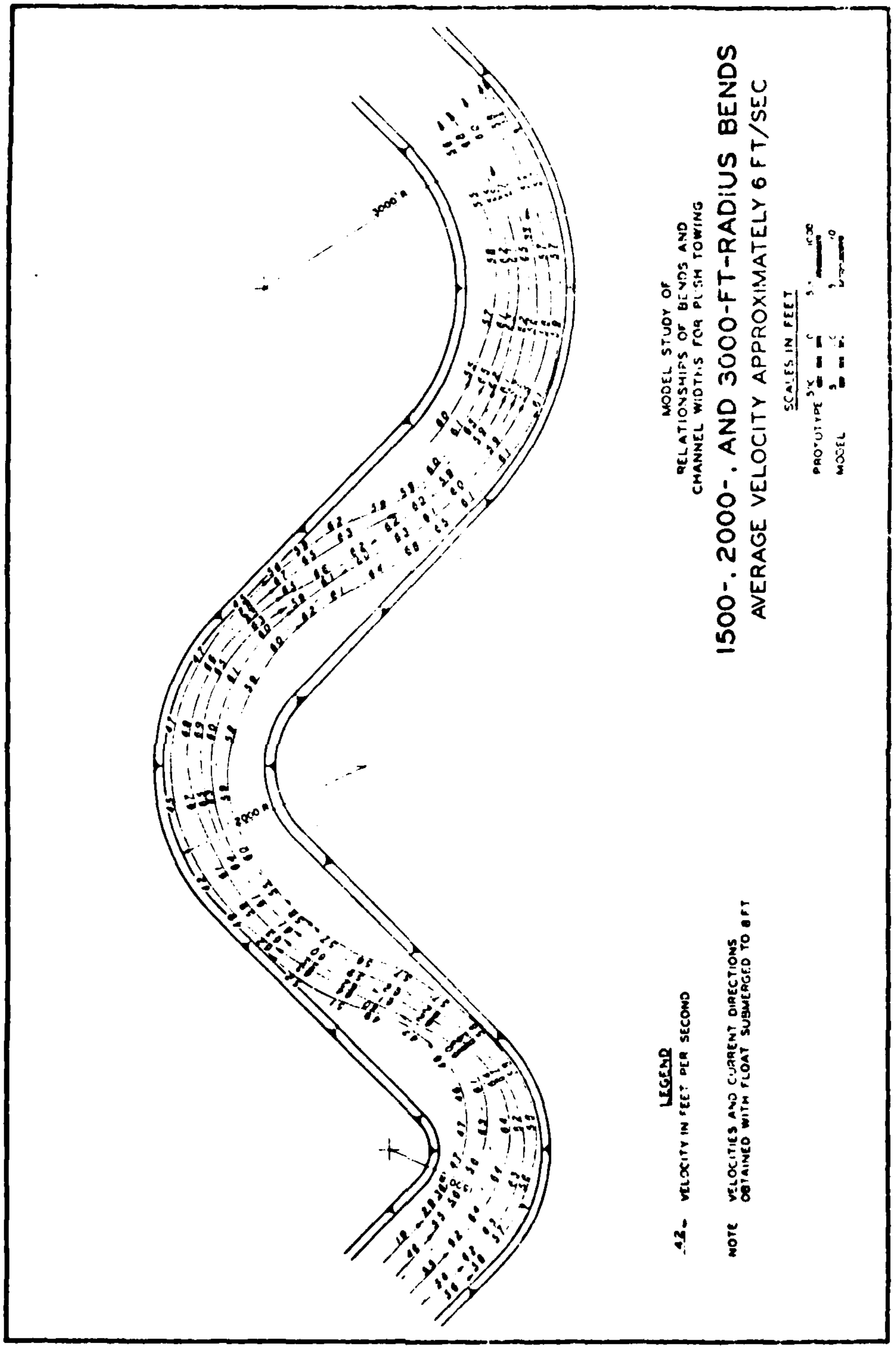
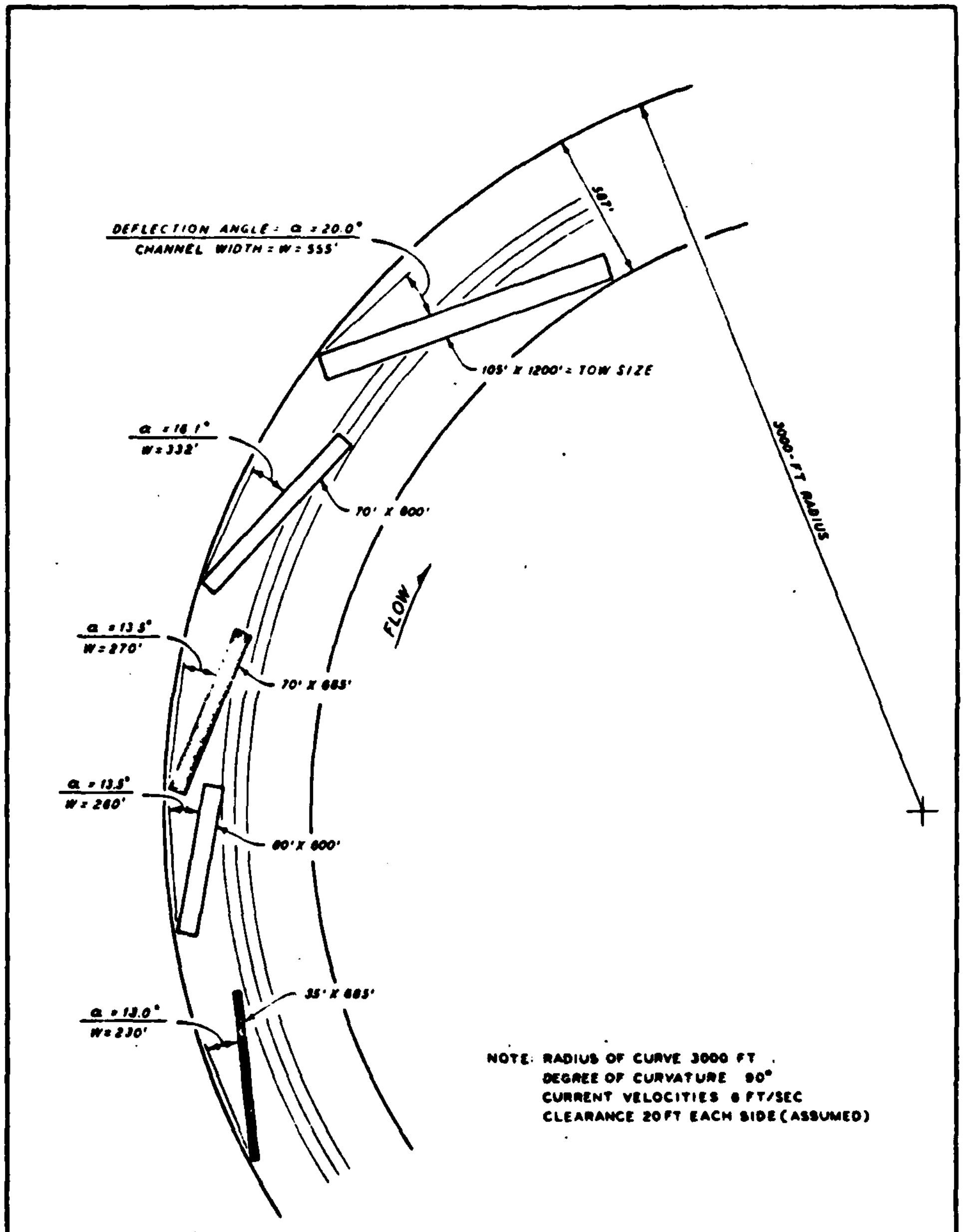

MODEL STUDY OF
RELATIONSHIPS OF BENDS AND
CHANNEL WIDTHS FOR PUSH TOWING
1500-, 2000-, AND 3000-FT-RADIUS BENDS
AVERAGE VELOCITY APPROXIMATELY 6 FT/SEC
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
4.2 VELOCITY IN FEET PER SECOND
NOTE VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO 8 FT
3000' R
2000' R

Figure 3



VARIATION OF DEFLECTION ANGLE AND CHANNEL WIDTH WITH TOW SIZES

Figure 4

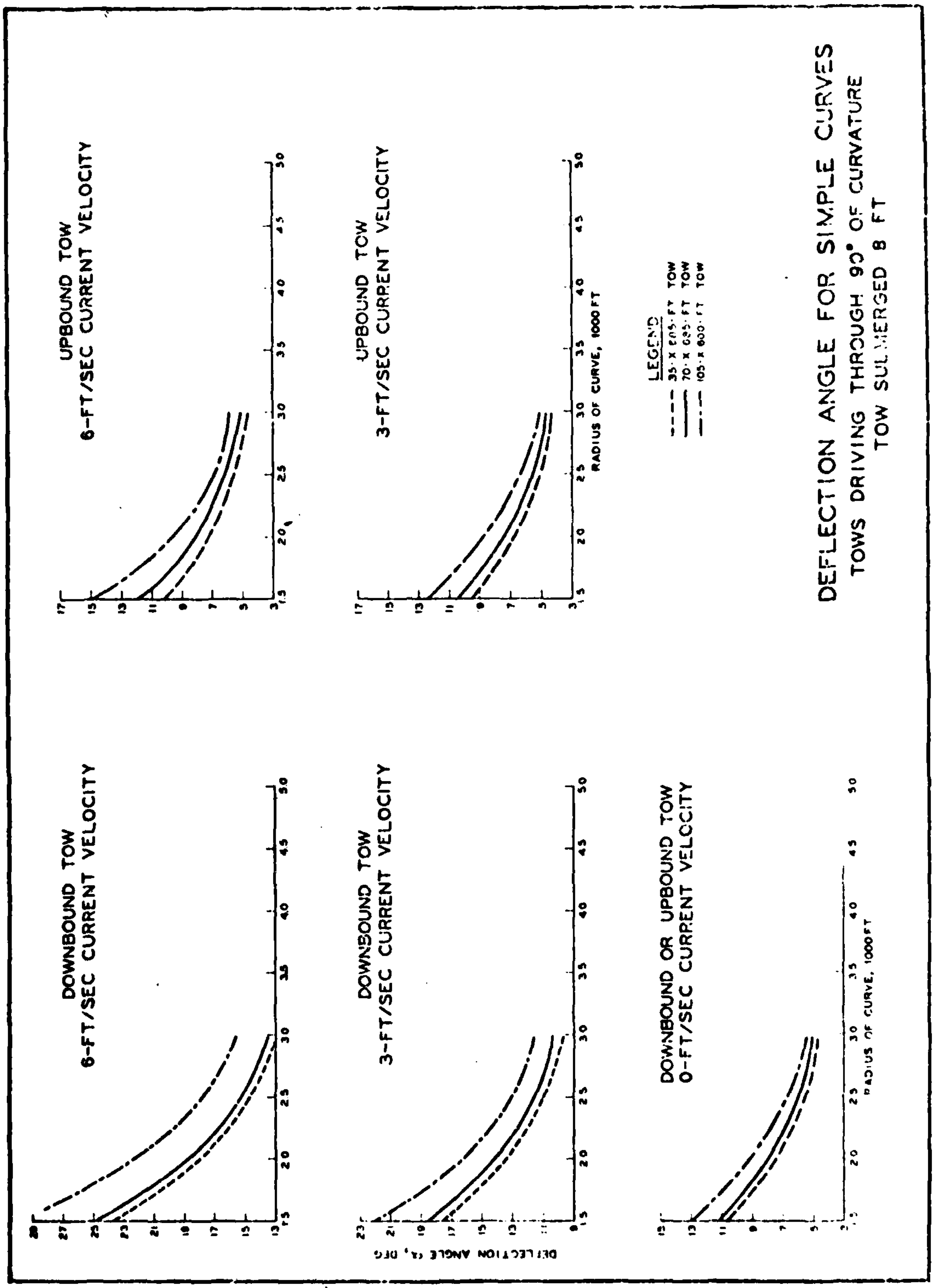
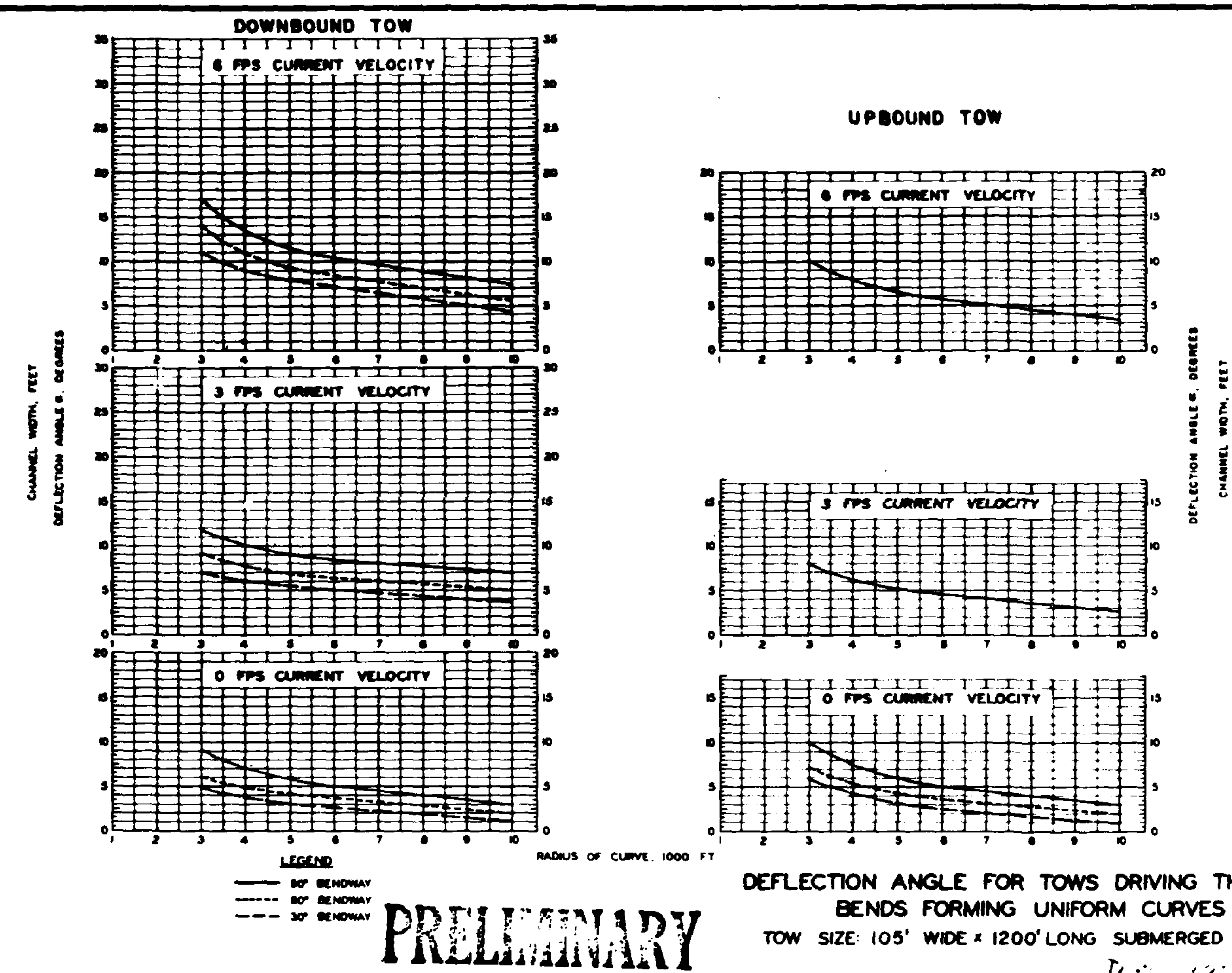

DEFLECTION ANGLE FOR SIMPLE CURVES
TOWS DRIVING THROUGH 90° OF CURVATURE
TOW SUBMERGED 8 FT
UPBOUND TOW
6-FT/SEC CURRENT VELOCITY
UPBOUND TOW
3-FT/SEC CURRENT VELOCITY
DOWNBOUND TOW
6-FT/SEC CURRENT VELOCITY
DOWNBOUND TOW
3-FT/SEC CURRENT VELOCITY
DOWNBOUND OR UPBOUND TOW
0-FT/SEC CURRENT VELOCITY
LEGEND
RADIUS OF CURVE, 1000 FT

Figure 5



DEFLECTION ANGLE FOR TOWS DRIVING THROUGH BENDS FORMING UNIFORM CURVES

TOW SIZE: 105' WIDE × 1200' LONG SUBMERGED 8 FT

GREAT I AREA BEND WIDTHS

NAME OF BEND	MILE	TO MILE	NORMAL WIDTH PRIOR DREDGING	NORMAL WIDTH POST DREDGING	WIDTH AT LAST SOUNDING	MAXIMUM POTENTIAL WIDTH	SUGGESTED WIDTH
Below Lock 1	846.3	846.7			150	200	150
Fort Snelling	845.7	846.3			200	250	200
Lower Mouth Minnesota River	843.8	844.3			250	300	300
Lilydale	841.7	842.4			300	350	300
Below Omaha R.R. Bridge	840.7	841.4			250	250	250
Above Beltline R.R. Bridge	835.7	836.3			400	500	400
Armour	832.9	833.6			400	400	400
Grey Cloud Slough	827.3	828.0	250	400	500	500	450
Pine Bend Head Light	825.0	826.2	200	400	350	400	400
Pine Bend Foot Light	823.3	824.3	250	375	350	375	375
Grey Cloud Landing	822.3	823.3	250	400	400	400	400
Boulanger Bend	820.3	821.5	250	450	500	500	500
Boulanger Bend Lower Light	818.4	820.3	250	450	450	500	400
Nininger	817.8	818.4	250	400	400	500	400
Upper Approach Lock 2	815.6	816.9			500	600	500
Hasting Highway Bridge	813.8	814.2			450	450	450
Point Douglas	812.4	813.0	250	400	400	500	400
Prescott, Wisconsin	810.0	810.7	300	450	500	600	450
Truedale Slough	808.2	808.8	200	350	350	400	400
Four Mile Island	807.2	807.8	300	450	500	500	500
Below Wind Creek	800.0	800.7	300	500	500	500	450
Below Diamond Bluff	798.7	799.5	250	400	400	500	400
Upper Approach Lock 3	797.0	798.4	300	600	600	700	600
Trenton, Wisconsin	794.0	794.5	200	600	600	650	600
Above Red Wing Hwy. Bridge	790.5	792.0	300	500	350 - 450	400 - 600	500

GREAT I AREA BEND WIDTHS (Cont')

NAME OF BEND	MILE	TO MILE	NORMAL WIDTH PRIOR DREDGING	NORMAL WIDTH POST DREDGING	WIDTH AT LAST SOUNDING	MAXIMUM POTENTIAL WIDTH	SUGGESTED WIDTH
Below Red Wing Hwy. Bridge	789.4	790.3	200	500	500	600	500
Goose Bay	787.5	788.6	200	350	350	400	350
Head of Lake Pepin	785.2	785.6	300	450	450	550	500
Reads Landing	762.4	763.3	100	450	500	600	500
Below Reads Landing	761.5	762.5	300	450	550	600	500
Crats Island	758.0	759.5	100	500	450	600	450
Beef Slough	753.7	754.6	200	400	400	450	400
Alma Lower Light	751.0	752.1			450	450	450
Upper Mouth of Zumbro River	794.4	751.0			500	550	500
Mule Bend	747.8	748.8	200	450	500	600	500
West Newton	747.0	747.8	250	450	400	600	450
Above Teepeeota Point	757.2	757.8	350	500	500	550	500
Lower Zumbro	744.9	745.4	350	500	500	650	500
Below West Newton	746.4	746.9	300	500	450	650	450
Summerfield Island	742.8	743.6	150	400	400	500	400
Minneiska, Minnesota	742.0	743.0			500	600	500
Mount Vernon Light	740.3	741.3	200	500	500	500	500
Richtman Light	739.3	740.3			550	600	550
Upper Approach Lock 5	738.1	739.0			500	500	500
Island 58	734.0	735.0	200	500	500	600	500
Fountain City	732.7	733.5	250	400	400	500	400
Head of Betsy Slough	731.7	732.3	250	500	500	600	500
Betsy Slough Bend	731.0	731.7	250	450	450	500	500
Wilds Bend	729.5	731.0	250	450	500	500	450
Island 71	726.0	726.7	300	450	450	500	450

GREAT I AREA BEND WIDTHS (Cont')

NAME OF BEND	MILE	TO MILE	NORMAL WIDTH PRIOR DREDGING	NORMAL WIDTH POST DREDGING	WIDTH AT LAST SOUNDING	MAXIMUM POTENTIAL WIDTH	SUGGESTED WIDTH
Gravel Point	721.6	722.4	300	500	600	600	500
Blacksmith Slough	718.0	719.0			550	700	550
Lamoille	715.6	716.6			500	600	500
Head of Richmond Island	712.6	713.4	250	450	400	600	450
Queens Bluff	711.0	712.0	200	500	500	600	500
Winters Landing	708.0	709.0	200	500	300	600	400
Dakota, Minnesota	706.0	707.4	150	400	400	500	400
Black River	698.0	698.7			600	600	600
Broken Arrow	695.8	696.8	300	500	450	600	450
Sand Slough	694.4	695.2	300	600	500	700	500
Two Mile Island	691.8	692.2			500	800	500
Above Brownsville	690.2	691.0	100	400	500	650	400
Brownsville	689.7	690.2	100	500	450	600	400
Head of Raft Channel	687.5	688.4	200	400	450	500	400
Below Head of Raft Channel	686.5	687.5	250	400	350	500	400
Deadmans Slough	685.5	686.5			400	500	400
Warners Landing	683.0	683.6			400	450	400
Island 126	677.2	678.2	250	500	450	600	450
Twin Island	676.0	677.3	150	400	500	600	400
Bad Axe Bend	674.0	675.0	300	600	450	600	450
Head of Battle Island	670.7	671.5	300	450	500	500	450
Battle Island	669.8	670.7			500	600	500
Lansing Upper Light	663.8	664.4	200	600	500	800	500
Above Lansing Bridge	663.4	663.8			450	550	450
Below Lansing	660.3	661.0	300	600	450	700	450

GREAT I AREA BEND WIDTHS (Cont')

NAME OF BEND	MILE	TO MILE	NORMAL WIDTH PRIOR DREDGING	NORMAL WIDTH POST DREDGING	WIDTH AT LAST SOUNDING	MAXIMUM POTENTIAL WIDTH	SUGGESTED WIDTH
Heytmans Crossing	654.5	655.5			500	500	500
Crooked Slough Foot Light	651.6	652.4			500	500	500
Gordons Bay	645.4	646.1	350	600	400	700	450
Mississippi Gardens	642.5	643.5	250	550	500	800	500
Johnsonport	640.6	641.8			500	600	500
Wyalusing Bend	628.6	629.3	300	600	600	700	500
Wyalusing	627.2	628.0	300	600	600	1,000	500
Catfish Slough	625.7	626.6			700	800	500
Clayton	624.7	625.7			750	900	500
French Island	619.8	620.6			500	800	500
McMillian Island	612.0	619.0	200	500	500	500	500
Ferry Slough	615.6	616.3	300	600	600	600	450
Upper Approach Lock 10	615.1	615.6			600	600	600

Definitions

-Normal width prior dredging - Continuous channel width at low control pool prior to initiation of maintenance dredging with a depth of 10.5 feet or greater. In many instances, maintenance dredging is accomplished prior to pool levels reaching low control pool and the width noted is not encountered in actual navigation.

-Normal width post dredging - Upon completion of dredging, the navigation buoys are moved to the edge of the dredge cut and are encountered at this location during navigation.

-Width at last sounding - Width of channel noted by navigation aids as of most recent survey. Adjustment of the buoys may have occurred since that time.

-Maximum potential width - Maximum theoretical dredging width which could be accomplished without wing dam modification or without changing the existing shoreline.

GREAT I AREA BEND WIDTHS (Cont')

Notes

The survey considered, but was not limited to, the following parameters:

1. Channel width should only provide for one-way bends. (Note - This parameter was considered for the purposes on this survey only. Its presentation here should not be interpreted as a statement of policy for any group.)

2. Channel width should be adequate to allow navigation under all conditions including high current, out draft, wind, etc.

3. Channel width shall include sufficient width to allow a realistic tolerance for clearance of wing dams, other fixed obstacles, and shallow water for safe operation of tows.

4. Additional width to allow for interim shoaling between dredging periods will not be considered. Independent sediment transport and hydraulic mechanics studies should be utilized to project such shoaling effects.

APPENDIX B

RECOMMENDATIONS AND JUSTIFICATIONS

APPENDIX B
RECOMMENDATIONS AND JUSTIFICATIONS

RECOMMENDATION

1. Average annual dredging quantities should be minimized through application of technically-supported reduced depths with minimum channel width suitable for navigation with exception for other specific recommendations.

JUSTIFICATION

This is the DRWG (Dredging Requirements Work Group) purpose. Depth of dredging should be determined by the best technology available including historical dredging experience, site characteristics, mathematical modeling, and physical modeling. Minimum channel width will be determined by the Channel Dimension Committee. The required width of channel depends on the depth of dredging as documented by the Permanent Navigation Congress Record. Combination of width and depth will be considered to determine the optimum condition to minimize dredging. The primary consideration will be to avoid creating a sediment trap during low flows by excessive depth or width of dredging.

RECOMMENDATION

2. Establish a committee to review channel dimensions maintained on the Upper Mississippi River navigation system. The committee would be led by

the Corps of Engineers with representatives from the U.S. Coast Guard, the navigation industry, and representatives from any other concerned State or Federal agencies.

JUSTIFICATION

The Commercial Transportation Work Group has recommended periodic review of channel widths maintained. The Fish and Wildlife Work Group has recommended continuation of the on-site inspection team process to review channel maintenance projects. Because of the frequency and remote locations of the on-site meetings, effective participation by the Coast Guard and navigation industry has not been possible. This committee would allow effective review by the best qualified participants from each concerned party.

RECOMMENDATION

3. The St. Paul District, Corps of Engineers, should complete the one-dimensional sediment transport mathematical modeling of the navigation system, including the parameters identified in the GREAT effort.

JUSTIFICATION

The DRWG has contracted for HEC-6-type sediment transport modeling from Lake Pepin to Genoa, Wisconsin (lower pool 4 through pool 8). This

modeling effort provides a reasonable estimate of the sediment transport continuity through the 9-foot channel system. It allows:

1. Increased sophistication in projecting optimum dredging depth to minimize dredging quantities without undue navigational risks.

2. Identification of approximate individual tributary sediment contribution and potential maintenance dredging benefits available through efforts to reduce tributary sediment discharge.

3. Consideration of tributary and main stem sediment traps.

4. Identification of river locations where channel alignment structure modification should be pursued to reduce dredging requirements.

5. A feasibility analysis of riverine placement of dredged material.

6. Provision for continuity for individual site evaluation by a two-dimensional math model or physical model to determine finite site requirements to minimize dredging quantities.

The Corps of Engineers is obtaining cross sections of pools 9 and 10 which will provide the basic field data, but additional cross sections will be required above Lake Pepin. Cross sections are available above locks and dam 2 from floodplain studies.

RECOMMENDATION

4. Review and further calibration of the two-dimensional math model developed by Colorado State University for GREAT should be completed if the initial model is considered to be a useful and cost effective tool.

JUSTIFICATION

The two-dimensional model constructed using sediment transport and hydraulic theory required significant adjustment to reproduce the Reads Landing prototype documentation and physical model data. This program adjustment and calibration requires further refinement considering more test sites to develop confidence in its application throughout the system. In layman's terms, in an equation $x + y = 9$, many values of x and y will result in the same end result of 9. But if we examine another condition where $x - y = 3$, only $x = 6$ and $y = 3$ will satisfy both conditions. Several conditions must be evaluated before we can be assured the model will work on the system and not at Reads Landing only. To allow further review and calibration, the Corps of Engineers should continue detailed monitoring of the Read's Landing-Chippewa River and other types of sites. The other types of sites should include a site with a major loss of flow into the backwaters, a site which is historically stable, a site including a major river bend, and a site with an evident wing dam design deficiency.

RECOMMENDATION

5. The river's sediment transport capability should be used to move sediment to the proximity of long-range disposal sites as feasible.

JUSTIFICATION

When GREAT I is completed, long-range sites for dredged material placement will be identified. Transporting dredged material from the historic dredging sites to these disposal sites is expensive in terms of cost and energy. The Corps should pursue modification of the submerged groin and closing dam system as environmentally and economically justified to effect this recommendation. The DRWG is testing the feasibility of this approach in the Reads Landing area using the University of Minnesota's constructed physical model. Riverine placement is not included in this recommendation but is considered under recommendation 9 because of its controversial nature.

RECOMMENDATION

6. The U.S. Army Corps of Engineers or the U.S. Coast Guard should establish a regulation requiring advance approval for use of a tow size larger than 107.5 feet wide or 1,200 feet long in the St. Paul District. This regulation would recognize the existing operator liability for any damage to the channel condition. If an increase in tow size is proposed for use other than trial

application which would require additional channel width, the Corps of Engineers should prepare an environmental impact statement (EIS) because increased channel width maintenance is considered to be a major Federal action.

JUSTIFICATION

The DRWG (Dredging Requirements Work Group) plan of study was developed considering the largest current tow size operating on the Upper Mississippi River because GREAT defined the existing 9-foot channel project as a given quantity. This tow size is 1,200 feet long and 107.5 feet wide with a draft of up to 9.0 feet. Any increase in tow dimension could increase channel maintenance requirements substantially. Increased tow dimensions were not analyzed by this work group. It is recognized that an EIS would probably be required to allow construction of a lock guidewall extension by the Corps, but use of "bow thrusters", motor vessel assistance at the locks, or other methods might be considered if economically feasible.

RECOMMENDATION

7. Dredging depths in approaches to rigid structures such as locks, bridges, piers, or other structures which pose potential safety hazards should be determined by technically supported safety criteria rather than by minimizing dredging quantities.

JUSTIFICATION

Rijkswaterstaat Communications No. 21, "Push Tows in Canals", documents that push tows lose directional stability whenever the water depth is less than

1.5 times the draft of the largest vessel. When compensation through improved channel alignment or additional channel width is unavailable (where rigid structures form the channel boundaries), depth of dredging should not be reduced in the interest of navigation safety and potential environmental contamination. A restricted channel section is defined as less than 300 feet of usable channel on tangent sections and less than the width of channel recommended by the Channel Dimension Committee on river bends.

RECOMMENDATION

8. Whenever beneficial use exceeds dredging requirements, or an individual demand will be unavailable in the future, dredging depth and width should be based on channel maintenance and navigational economy.

JUSTIFICATION

The purpose of minimizing dredging quantities is to reduce environmental impacts of material placement and minimize cost of dredging and related material transport. When the recommended conditions exist, minimizing dredging quantity does not meet the established purpose and may cause adverse impacts at alternate borrow sources.

RECOMMENDATION

9. Riverine disposal should be investigated for adoption where recommended beneficial uses are unavailable and where secondary environmental impacts of riverine placement are less than alternate placement sites. Field tests would be limited to small quantities of clean, nonradioactive tracer materials.

JUSTIFICATION

GREAT II has documented a net loss of nearly 500,000 cubic yards of bottom sediment in less than 1 mile of channel in a 6-week period. In situations where dredging quantities are small in comparison to the natural sediment transport volume, riverine disposal may be feasible, and alternate disposal impacts could be avoided. Riverine disposal would not be recommended where the impacts on downstream dredging requirements, navigation, water quality, winter fisheries, or backwater sedimentation are excessive. Investigation has been restricted to one minor field application at Reads Landing, mile 762.5, in 1975 and ongoing physical and mathematical model research.

RECOMMENDATION

10. The condition of all wing dams and closing dams at all historic dredging sites in the St. Paul District should be investigated. Repair and/or modification based on a one-dimensional sediment transport math model should be considered. Site specific recommendations should be developed for individual sites using more sophisticated math or physical modeling, if necessary. The Corps of Engineers should request funding and should program any justified rehabilitation.

JUSTIFICATION

Dredging quantity and placement impact could be reduced at the benefit of the total system. The existing system was constructed before the 9-foot channel project. Limited field surveys and engineering reviews accomplished by the Corps justify review at several sites. Specific sites are noted in the main report.

RECOMMENDATION

11. A narrated film illustrating the river mechanics operating on the Mississippi River and the logic of channel maintenance techniques should be developed. This film could be cosponsored with an interested academic institution.

JUSTIFICATION

The film would inform the concerned agencies' officials and the public of the system and gain support for necessary management, operation and maintenance programs. A basic understanding of the river mechanics would allow reasonable consideration.

RECOMMENDATION

12. The operation of dams or construction of low-head dams to create a more favorable Mississippi River stage in relation to tributary stages should be investigated.

JUSTIFICATION

The physical and mathematical model research shows that the Mississippi River stage is a critical factor governing the sediment contribution of the Chippewa River. Minor stage adjustments at the Chippewa-Mississippi Rivers confluence could at least temporarily minimize dredging requirements. The sediment might be trapped for off-channel dredging or naturally assimilated during the next spring high flow.

RECOMMENDATION

13. The possibility of applying the concept of unit stream power and the theory of minimum rate of energy expenditure should be studied to determine the optimum channel geometry, pattern, and profile of the Upper Mississippi River and its major tributaries. As available upon development by the Vicksburg District, a model to review long-term channel alignment as channel alignment structure repair and/or modification is required should be used.

JUSTIFICATION

Data collected by the Lower Mississippi Valley Division of the Corps indicate that the rate of sediment transport and the responses of the Lower Mississippi River and some of its tributaries to human activities are consistent with the concept of unit stream power and the theory of minimum rate of energy expenditure. This theory treats a river as a system to determine the optimum channel geometry, pattern, and profile under different hydraulic,

hydrologic, geologic, and man-made constraints so that the overall channel maintenance effort can be minimized. A computer model based on this theory is being developed for the Vicksburg District of the Corps. In the long term, this would improve overall channel alignment design to minimize dredging requirements and channel alignment maintenance.

RECOMMENDATION

14. The U.S. Coast Guard's capability to operate and maintain the navigational aid system should be increased.

JUSTIFICATION

The 2nd Coast Guard District has one buoy tender, the WYACONDA, assigned to maintain over 500 miles of channel aids in the St. Paul and Rock Island Districts. During spring breakup, hundreds of buoys are displaced. During 1978, several groundings occurred at Dakota, Minnesota, because the WYACONDA was working in other critical reaches.

RECOMMENDATION

15. A sediment trap should be established on the Chippewa River above the Burlington Northern Railroad Bridge and on other tributaries as feasible and economically justified.

JUSTIFICATION

Initial contract research indicates approximately 90 percent of the Chippewa River bed load is dredged in the Mississippi River 9-Foot Channel Project. If this proves correct, it might be economical to station a small dredge, such as the DUBUQUE, to intercept the material before it reaches the 9-foot channel. The exact location should be determined by the location of a suitable stockpile site and the suitability for trap efficiency. Other tributaries should be considered under the research noted in recommendation 3. Existing contract effort will examine the potential impact of the bed load sediment loss on structures such as lock and dam 4 and on the existing wing dam and closing dam system to assure that the Mississippi River response is acceptable.

RECOMMENDATION

16. A thorough literature search and necessary supplemental research are recommended to document the impact of channel depth on required channel width to maintain navigational safety.

JUSTIFICATION

Field tests of reduced depth dredging did not include any channel width adjustments. Field experience in the GREAT reduced depth dredging program illustrated that the tows had to reduce their velocity to avoid groundings. As documented in the main report, reduced tow velocity improves tow directional stability within physical limitations. However, motor vessel operators

report loss of backing rudder power and loss of capability to respond to changing river current and wind impacts. Participants in the National River Pilots Association reported a net loss in operational safety. These research data are essential to allow sound decisions by the channel dimensions committee.

RECOMMENDATION

17. Reduced depth dredging should be avoided when it increases the frequency and cost of dredging without a decrease in average annual dredging quantity.

JUSTIFICATION

The purpose of reduced depth dredging is to reduce dredging quantity. If reduced-depth dredging only increases cost without a decrease in overall dredging quantity, it is obviously undesirable. Decisions for individual sites should be based on technically supported research or long-term field experience.

RECOMMENDATION

18. Channel maintenance should be deferred until the channel depth reaches a depth of 10.5 below low control pool (LCP) with the following exceptions:

a. Approaches to structures which form rigid channel boundaries. This initiating depth should be determined by the channel dimension committee.

b. Sites which constitute sediment traps and will not stabilize naturally.

c. Sites which have a history of closing navigation.

JUSTIFICATION

Dredging proved unnecessary at several sites during the field tests because the sites stabilized deeper than 10.5 feet. However, dredging should be initiated earlier to assure safe navigation or as cost effective at other sites where natural stabilization will not occur at depths greater than 10.5 feet. Examples of these are:

a. Structural boundaries - locks, bridges, and piers.

b. Sediment traps - Soo Line Railroad Bridge, mile 857; above the Savage Railroad Bridge, mile 14.5; St. Paul Barge Terminal.

c. Closure History - Reads Landing, mile 762.5, and Crats Island, mile 759, in pool 4.

RECOMMENDATION

19. Long-term planning for all channel maintenance activities and elements should be supported with necessary funding and personnel. When unresolved site specific conflicts exist during the navigation season, the Corps of Engineers should initiate necessary coordination and permit applications no later than when the channel reaches a depth of 11 feet below LCP whenever possible.

JUSTIFICATION

During the GREAT pilot program, dredging was programmed when the depth reached 10.5 feet below LCP. Although initiation of dredging is not generally recommended at 11 feet, initiation of further coordination at 11 feet would allow increased lead time before dredging becomes critical or hazardous.

RECOMMENDATION

20. The Corps of Engineers monitors the deltas at the confluence of major bed load supplying tributaries with the Mississippi River. Technical relationships of delta condition, hydrologic occurrences, and risk to downstream channel condition should be developed. The Corps of Engineers should initiate dredging with full consideration of environmental impacts at the dredging site and material placement site when the technical relationships indicate a high risk of potential channel closure.

JUSTIFICATION

The University of Minnesota physical model has illustrated that the 100,000-cubic-yard dredge cut made in May 1978 can fill in 35.6 days when the delta condition is adverse, with a flow of 19,000 cubic feet per second (cfs) in the Mississippi River and 30,000 cfs in the Chippewa River. When an additional 100,000-cubic-yard dredge cut is made in the Chippewa River delta, similar shoaling at Reads Landing with the same discharge relationship takes 60 days

to fill the Reads Landing dredge cut. Development of the delta relationships with suitable preventive dredging by the Corps could reduce emergency dredging, allow improved advance coordination of dredging, and greatly improve the reliability of navigation. To allow implementation, the technical relationships should be completed for the Chippewa River and programmed for other tributaries. Data collection at the Cannon, Zumbro, Root, Upper Iowa, and Wisconsin Rivers should be initiated as soon as feasible to provide a better data base in developing delta relationships.

RECOMMENDATION

21. Low control pool elevation should be recomputed above the primary control point considering a minimum base flow condition.

JUSTIFICATION

The present low control pool definition above the primary control point is based on zero river discharge. If a minimum discharge is considered, the LCP definition will be a higher minimum water surface. This would reduce, at least temporarily, dredging quantities because the depth of dredging is established relative to LCP elevation. A minimum discharge is considered more suitable because a zero discharge has not been encountered in the recorded history.

RECOMMENDATION

22. All dredging modifications or alternatives found feasible in the progress contracts with Colorado State University and the University of Minnesota should be further investigated for environmental and economic acceptability and implemented as feasible.

JUSTIFICATION

Results of the one- and two-dimensional mathematical models and the physical model will not be complete when the GREAT report is completed. The mathematical models are new tools needed to evaluate dredging alternatives. The GREAT time period has been used to develop these tools. It is only now, at the end of the GREAT study, that these tools are available. When the contracts are completed, several alternatives will probably be recommended that can reduce dredging quantities or impacts. However, the contracts will not evaluate the economic or environmental acceptability of the alternatives. Before any alternatives are implemented it will be necessary to do this evaluation as well as determine final design of the alternatives.

RECOMMENDATION

23. The Mississippi River 9-foot channel sediment transport characteristics from the Wisconsin River confluence to Guttenberg, Iowa, should be investigated to determine the factors which result in minimal maintenance dredging.

JUSTIFICATION

The Wisconsin River is known to carry a heavy sediment bed load. However, maintenance dredging quantities downstream of the Wisconsin-Mississippi River confluence are very low. Channel conditions which permit this phenomenon of high bed load transport may be applicable for modification of the channel at other sites.

APPENDIX C

GLOSSARY

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GLOSSARY

Acre-Foot. A unit for measuring the volume of water equal to the quantity of water required to cover 1 acre to a depth of 1 foot (43,560 cubic feet or 325,851 gallons). The term is commonly used in measuring volumes of water used or stored.

Aggradation. A process of raising a land surface by the deposition of sediment.

Alluvial Channel. A channel whose bed is composed of noncohesive sediment that has been or can be transported by the flow.

Alluvial Fan. An alluvial deposit of a stream where it issues from a gorge upon an open plain.

Alluvial Plain. A plain formed by the deposition of alluvial material eroded from areas of higher elevation.

Alluvium (Alluvial Deposit). Clay, silt, sand, gravel, pebbles or other detritus deposited by water.

Antidunes. Bed forms of curved, symmetrically-shaped sand waves that may move upstream, remain stationary, or move downstream. They occur in trains that are in phase with and strongly interact with gravity water-surface waves. The water-surface waves have larger amplitudes than the coupled sand waves. At large Froude numbers,

the waves generally move upstream and grow until they become unstable and break like surf (breaking antidunes). The agitation accompanying the breaking obliterates the antidunes, and the process of antidune initiation and growth is repeated. At small Froude numbers, the antidunes generally remain stationary and increase and decrease in amplitude without breaking (standing waves).

Apron. An adjunct to a dam or other structure, consisting of a surface protection against erosion.

Backwater. Water backed up or retarded in its course as compared with its normal or natural condition of flow. In stream gaging, a rise in stage produced by a temporary obstruction such as ice or weeds or by the flooding of the stream below.

Backwater Curve. A longitudinal profile of the water surface in a stream where the water surface is raised above its normal level by a natural or artificial obstruction.

Bank. The margins of a channel. Banks are called right or left as viewed facing the direction of the flow.

Bankfull Stage. The stage at which a stream first overflows its natural bank.

Bars. Bed forms having lengths of the same order as the channel width or greater, and heights comparable to the mean depth of the generating flow.

Bars, Alternate. Bars occurring in straighter reaches of channels and tending to be distributed periodically along the reach, with consecutive bars on opposite sides of the channel. Their lateral extent is significantly less than the channel width.

Bars, Middle (or Transverse). Bars occurring in straight channels and occupying the full channel width.

Bars, Point. Bars occurring adjacent to the convex bank of channel bends.

Bars, Tributary. Bars occurring immediately downstream from points of lateral inflow into a channel.

Bed (Streambed). The bottom of a watercourse.

Bed Configuration. A complex of bed forms covering the bed of an alluvial stream.

Bed Form. A generic term used to denote any irregularity produced on the bed of an alluvial channel by flowing water and sediment.

Bed Layer. A flow layer, several grain diameters thick (usually taken as two grain diameters thick) immediately above the bed.

Bed Load. That part of the total sediment load that moves by rolling or sliding along the bed. The term "bed load" may be used to designate either coarse material moving on or near the bed or material

collected in or computed from samples collected in a bed load sampler or trap. In other words, bed load is load which is not sampled by a suspension load sampler.

Bed-Load Discharge Sampler. A device to measure the discharge of bed load over part or all of the stream width.

Bed Material. The material comprising a streambed.

Bed-Material Discharge. A sediment discharge that consists of particles large enough to be found in appreciable quantities in the streambed.

Bed-Material Load. That part of the total sediment load which is composed of grain sizes represented in the bed--equal to the transport capacity of the flow.

Beneficial Use Site. An area where dredged material is temporarily stored until it can be used for some purpose outside the floodplain.

Benthic Community. A group of plants or animals living in or on the streambed.

Braiding of River Channels. The successive division and rejoining (of river-flow) with accompanying islands is the important characteristic denoted by the synonymous terms, braided or anastomosing stream. (Leopold and Wolman, 1957, p. 40) A braided stream is composed of anabranches.

Breaking Antidune. Curved symmetrically shaped waves on the water surface and channel bottom that build up with time and break like surf.

Capacity. The ability of a stream current to transport in terms of quantity.

Capture. Diversion of the flow of water in the upper part of a stream by the headward growth of another stream.

Channel. (1) The deepest portion of a riverbed, in which the main current flows. (2) A natural or artificial clearly distinguished waterway which periodically or continuously contains moving water or which forms a connecting link between two bodies of water.

Channel, Backwater. Side channels which do not carry appreciable flows even at high stage.

Channel, Side. Smaller channels in a reach of river where islands divide the reach into one or more channels. The larger is referred to as the main or thalweg channel.

Channel, Stable. A channel in which accretion balances scour on the average.

Channel, Straight. A channel having its sinuousity less than 1.5.

Chute. The natural or artificial steep-sloped reach of an open channel.

Chute and Pools. The flow phenomenon and bed configuration accompanying flows that occur at steep slopes and large bed-material discharges. The flow occurs at slopes steeper than for antidunes and consists

of a series of pools in which the flow is tranquil, connected by steep chutes where the flow is rapid. A hydraulic jump forms at the downstream end of each chute where it enters the pool. The bed configuration consists of triangle-shaped elements with a steep upstream slope; a flat, almost horizontal, back; and a gentle downstream slope. The chutes and pools move slowly upstream.

Clay. Sediment finer than 0.004 mm (millimeter) in diameter regardless of mineral composition.

Compentency. The ability of currents to transport in terms of dimensions of particles.

Confluence. The joining, or the place of junction, of two or more streams.

Contact Load. Sediment particles that roll or slide along in almost continuous contact with the streambed (often used synonymously with bed load).

Control. A natural constriction of the channel, long reach of the channel, stretch of rapids, or artificial structure downstream from a gaging station that determines the stage-discharge relation at the gage.

Critical Flow. Flow conditions at which the discharge is a maximum for a given specific energy or the specific energy is minimum for a given discharge.

Crossing and Pool. A series of shoals (crossings or bars) and deep pools exhibited in rivers.

Crossover. The relatively short and shallow length of a river between bends.

Cross Section (of a Stream). That section of the stream at a right angle to the main (average) direction of flow.

Cubic Feet per Second (ft^3/sec). A unit expressing rates of discharge. One cubic foot per second is equal to the discharge of a stream of rectangular cross section, 1 foot wide and 1 foot deep, flowing water an average velocity of 1 foot per second.

Cusec. This abbreviation for cubic foot per second common in the British Commonwealth countries (except Canada). It is not used by the U.S. Geological Survey; which uses ft^3/sec or cfs.

Cut-off (Cutoff). The direct channel, either natural or artificial, connecting two points on a stream, thus shortening the length of the channel and increasing its slope.

Degradation. The disintegration and wearing down of the surface of rocks, cliffs, strata, streambeds, etc., by atmospheric and aqueous action.

Delta. An alluvial deposit at the mouth of a river and the geographical and geomorphological unit which results from it.

Density, Water-Sediment Mixture. The bulk density which is the mass per unit volume including both water and sediment.

Depth-Integrated Sample. A water-sediment mixture that is accumulated continuously in a sampler that moves vertically at an approximately constant transit rate between the surface and a point a few inches above the bed of a stream and that admits the mixture at a velocity about equal to the instantaneous stream velocity at each point in the vertical. Because the sampler intake is a few inches above the sampler bottom, there is an unsampled zone a few inches deep just above the bed of the stream.

Detritus. Any loose material that results directly from rock disintegration, expecially when composed of rock fragments--contrasted with soil. In the sediment field, detritus has generally been used to designate the coarser material moved or deposited.

Discharge. In its simplest concept, discharge means outflow; therefore, the use of this term is not restricted as to course or location and it can be applied to describe the flow of water from a drainage basin. If the discharge occurs in some course or channel, it is correct to speak of the discharge of a canal or river. It is also correct to speak of the discharge of a canal or stream into a lake, stream, or ocean.

Discharge-Weighted Concentration. The dry weight of sediment in a unit volume of stream discharge or the ratio of the discharge of dry weight of sediment to the discharge by weight of water sediment mixture.

Disposal, On-Land. The disposal of dredged material on land at locations where the materials are not influenced by water stage fluctuation.

Disposal, Open Water. The disposal of dredged material on islands, marshes, and along riverbanks at locations where these materials are subject to the influence of river stage fluctuations or are readily washed back into the river by rainfall.

Disposal, Thalweg. The disposal of dredged material into the main channel.

Diversion. The taking of water from a stream or other body of water into a canal, pipe, or other conduit.

Diversion Dam. A dam built to divert part or all of the water from a stream into a different course.

Drainage Basin. A part of the surface of the earth occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

Drainage Divide. The rim of a drainage basin.

Dredging. A process by which sediments are removed from the bottom of streams, lakes, and coastal waters, transported by ship, barge, or pipeline, and discharged in open water or on land.

Dunes. Large bed forms having triangular profiles, a gentle upstream slope, and a steep downstream slope. They form in tranquil flow and, thus, are out of phase with any water-surface disturbance that they may produce. They travel slowly downstream as sand is moved across their comparatively gentle, upstream slopes and deposited on their steeper, downstream slopes. The downstream slopes are approximately equal to the angle of repose of the bed material. Dunes are smaller than sand bars but larger than ripples. They generally form at higher velocities and larger sediment discharges than do ripples, but at lower velocities and smaller sediment discharges than do antidunes. However, ripples form on the upstream slopes of dunes at lower velocities.

Eutrophication. The process by which waters become more eutrophic (richer in dissolved nutrients required for the growth of aquatic plants such as algae) either as a natural phase in the maturation of a body of water or artificially (as by fertilization and pollution).

Evapotranspiration. The water withdrawn from a land area by evaporation from water surfaces and moist soil and plant transpiration.

Explicit Finite Difference Method. A method for the solution of numerical approximations of differential equations. With this method, the value of a variable at a new time step is found from the known values at previous time steps.

Fall Diameter or Standard Fall Diameter. The diameter of a sphere that has a specific gravity of 2.65 and the same terminal uniform settling velocity as the particle (any specific gravity) when each is allowed to settle alone in quiescent distilled water of infinite extent and at a temperature of 24°C.

Fall Velocity. The average terminal settling velocity of a particle falling alone in quiescent, distilled water of infinite extent.

Fine Sediment. That part of the sediment discharge that consists of sediment so fine that it is about uniformly distributed in the vertical and is only an inappreciable fraction of the sediment in the streambed (referred to by some writers as wash load). Its upper size limit at a particular time and cross section is a function of the flow as well as of the sediment particles.

Flood. An overflow or inundation that comes from a river or other body of water (Barros, 1948) and causes or threatens to cause damage. Any relatively high streamflow overtopping the natural or artificial banks in any reach of a stream (Leopold and Maddock, 1954, pp. 249-251).

Flood-Frequency Curve. (1) A graph showing the number of times per year on average, plotted as abscissa, that floods of magnitude, indicated by the ordinate, are equaled or exceeded. (2) A similar graph but with intervals of floods plotted as abscissa.

Flood Peak. The highest value of the stage or discharge attained by a flood; thus, peak stage or peak discharge. Flood crest has nearly the same meaning, but since it connotes the top of the flood wave, it is properly used only in referring to stage--thus, crest stage, but not crest discharge.

Floodplain. A strip of relatively smooth land bordering a stream, built of sediment carried by the stream and dropped in the slack water beyond the influence of the swiftest current. It is called a living floodplain if it is overflowed in times of high water; but a fossil floodplain if it is beyond the reach of the highest flood.

Flood Routing. The process of determining progressively the timing and shape of a flood wave at successive points along a river.

Flood Stage. The stage at which overflow of the natural banks of a stream begin to cause damage in the reach in which the elevation is measured.

Flood Wave. A distinct rise in stage culminating in a crest and followed by recession to lower stages.

Floodway. A part of the floodplain which, to facilitate the passage of floodwater, is kept clear of encumbrances.

Flow-Duration Curve. A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.

Flow, Free Surface. The flow of water in which an interface exists between air and water.

Flow, Gradually Varied. The varied flow in which the velocity or depth changes gradually over a long distance.

Flow Laminar. The flow of a fluid in which the viscous forces are predominant. In channel flow, the fluid particles move approximately in definite, relatively smooth paths with no significant transverse mixing. In channel flow, it occurs at Reynolds numbers smaller than 500-2000 and in flow through porous media at Reynolds numbers smaller than 1-10.

Flow, Nonuniform. The flow in which the velocity vector is not constant along every streamline.

Flow, Open Channel. Flowing water having its surface exposed to the atmosphere.

Flow, Rapidly Varied. Varied flow in which the velocity or depth changes abruptly over a comparatively short distance.

Flow Regime. A range of flows producing similar bed forms, resistance to flow, and mode of sediment transport.

Flow, Sheet. The flow in a relatively thin sheet, of nearly uniform thickness over the soil surface.

Flow, Steady. The flow in which the velocity is constant in magnitude or direction with respect to time.

Flow, Turbulent. The flow with turbulence. In channel flow, it occurs at Reynolds numbers larger than approximately 5,000.

Flow, Uniform. The flow in which the velocity vector is constant along every streamline.

Flow, Unsteady. The flow in which the velocity changes in magnitude or direction with respect to time.

Flow, Varied. The flow in which velocity or depth changes along the length of the channel.

Fluvial Sediment. Fragmentary material that originates from weathering of rocks and is transported by, suspended in, or deposited from water.

Froude Number. A dimensionless number that relates the inertia forces to the gravitational forces and is important wherever the gravity effect is dominating, such as with water waves and flow in open channels.

Gage Height. The water-surface elevation referred to some arbitrary gage datum. Gage height is often used interchangeably with the more general term stage although gage height is more appropriate when used with a reading on gage.

Gaging Station. A particular site on stream, canal, lake, or reservoir where systematic observations of gage height or discharge are obtained.

Geology. The science which treats of the earth, the rocks of which it is composed, and the changes which it has undergone or is undergoing.

Geomorphology. The study of the characteristics, origin, and development of land forms.

Groins. Embankments that project a certain distance into the stream at some angle to the bank. They deflect the flow toward the center of the channel, thereby transferring scour from the banks to the center of the channel.

Hydraulic Jump. The sudden passage of water in an open channel from supercritical depth to subcritical depth accompanied by energy dissipation.

Hydraulic Radius. The cross-sectional flow area of a conduit divided by its wetted perimeter.

Hydraulics. The science treating of the laws governing water or other liquids in motion and their applications in engineering.

Hydrograph. A graph showing stage, flow, velocity, or other properties of water with respect to time.

Implicit Finite Difference Method. A method for the solution of numerical approximations of differential equations. With the implicit method, the value of a variable at a new time step is found from

the known value at previous time steps and from the unknown values of other variables at the new time step. The values of all variables at the new time step must be solved simultaneously.

<u>Islands</u>. The vegetated areas within the channel banks separated from the mainland by the main channel and side channel.

<u>Levee</u>. A water-retaining earthwork used to confine streamflow within a specified area along the stream or to prevent flooding caused by waves or tides.

<u>Levee, Natural</u>. Low alluvial ridge adjoining the channel of a stream, composed of sediment deposited by floodwater which has overflowed the banks of the channel.

<u>Load (Sediment Load)</u>. The sediment that is being moved by a stream. (Load refers to the material itself and not to the quantity being moved.)

<u>Load, Bed</u>. That part of the total sediment load that moves by rolling or sliding along the bed.

<u>Load, Bed-Material</u>. That part of the total sediment load which is composed of grain sizes represented in the bed--equal to the transport capacity of the flow.

Load, Suspended. That part of the total sediment load that is supported by by upward components of turbulence and stays in suspension for an appreciable length of time.

Load, Total Sediment. The sum of the bed-material load and the wash load, or bed load and suspended load, or measured and unmeasured load.

Load, Wash (Fine Material). That part of the total sediment load which is composed of particle sizes finer than those represented in the bed--determined by available bank and drainage area supply rate.

Lower Flow Regime. A category for flows producing bed forms of ripples, ripples on dunes, or dunes. In this flow regime, flow is tranquil, water-surface undulations are out of phase with bed undulations, and resistance to flow is large.

Meander. One curved portion of a sinuous or winding stream channel, consisting of two consecutive loops, one turning clockwise and the other counterclockwise.

Meander Belt. That part of the valley floor situated between two parallel lines tangential to successive, fully developed meanders at their extreme limits.

Meander Length. The distance along the river between two corresponding points at the extreme limits of two successive, fully developed meanders.

Meander Width. The amplitude of swing of a fully developed meander, measured from midstream to midstream.

Measured (Sampled) Zone. Because of the design of the various depth integrating sediment samplers, there is a physical constraint on the depth to which a sample can be taken. Most sediment samplers can measure to within 0.3 foot of the bed. Above this point is termed the sampled or measured zone; below, the unmeasured zone.

Median Diameter. The midpoint in the size distribution of sediment such that half the weight of the material is composed of particles larger than the median diameter and half is composed of particles smaller than the median diameter.

Morphology, Fluvial. The science of the formation of beds and floodplains and forms of streams by the action of water.

One-Dimensional. When applied to mathematical modeling of rivers, this means the variation of flow, velocity, depth, bottom elevation, etc., is only considered in one direction, along the centerline of the river.

Outdraft. The movement of flow in a direction not parallel to the main channel. Flow leaving the channel to a backwater area would cause an outdraft.

Ox-Bow. The abandoned part of a former meander, left when the stream cut a new, shorter channel.

Plane Bed. A bed form in which there are no irregularities larger in amplitude than a few grain diameters.

Point-Integrated Sample. A water-sediment mixture that is accumulated continuously in a sampler that is held a relatively fixed point in a stream and that admits the mixture at a velocity about equal to the instantaneous stream velocity at the point.

Pool. A deep reach of a stream. The reach of a stream between two crossings. Natural streams often consist of a succession of pools and crossings.

Reach. (1) The length of a channel for which a single gage affords a satisfactory measure of the stage and discharge. (2) The length of a river between two gaging stations. (3) More generally, any length of river.

Recurrence Interval (Return Period). The average interval of time within which a given flood will be equaled or exceeded once.

Regime. "Regime theory" is a theory of the forming of channels in material carried by the streams. Used in this sense, the word "regime" applies only to streams that make at least part of their boundaries from their transported load and part of their transported load from their boundaries, carrying out the process at different places

and times in any one stream in a balanced or alternating manner that prevents unlimited growth or removal of boundaries. A stream, river, or canal of this type is called a regime stream, river, or canal. A regime channel is said to be "in regime" when it has achieved average equilibrium, that is, the average values of the quantities that constitute regime do not show a definite trend over a considerable period--generally of the order of a decade. In unspecialized use "regime" and "regimen" are synonyms.

Riffles. Shallow rapids in an open stream, where the water surface is broken into waves by obstructions totally or partly submerged.

Ripples. Small triangle-shaped bed forms that are similar to dunes but have much smaller and more uniform amplitudes and lengths. Wave lengths are less than about 2 feet, and heights are less than about 0.2 foot.

River Bed. The lowest part of a river valley shaped by the flow of water and along which most of the sediment and runoff moves in interflood periods.

River Mile. A river mile of a section is the mileage between the section and a reference point along the river thalweg or main-flow path.

River Training. Engineering river works built to direct the flow, lead it into a prescribed channel, or increase the water depth for navigation and other uses.

River Width. The distance between vegetated banks taken normal to the general direction of flow in the river.

Sand. Sediment particles that have diameters between 0.062 and 2.0 mm.

Sandbar. A dune-shaped bed form whose upstream surface is extremely long in relation to the geometry of the channel (length is two to three times the width of the channel). The bar may often protrude above the flow.

Sand Waves. Crests and troughs (such as ripples, dunes, sandbars, antidunes, or standing waves) on the bed of an alluvial channel that are formed by the movement of the bed material.

Scour. Erosive action--particularly, pronounced local erosion--of water in streams in excavating and carrying away materials from the bed and banks.

Secondary Currents. Movement of water particles on a cross section perpendicular to the longitudinal direction of the channel.

Sediment. Fragments that orginate from weathering of rock and are transported by, suspended in, or deposited by water or air.

Sediment Concentration. The ratio of dry weight of sediment to total weight of the water-sediment mixture, expressed in parts per million.

Sediment Discharge. The amount of sediment that is moved by water past a section in a unit of time.

Sediment Yield. The total sediment outflow from a watershed or a drainage area at a point of reference and in a specified period of time. This is equal to the sediment discharge from the drainage area.

Shear Stress. The internal fluid stress which resists deformation.

Shingle. Gravel and cobblestones deposited by water to resemble lapped roofing pieces. The origin is "shingl"—a Norwegian term for a small round stone.

Shoaling. The creation of a shallow area by a sand wave or bar.

Sieve Diameter. The size of a sieve opening through which the given particle will just pass.

Silt. Sediment particles whose diameters are between 0.004 and 0.062 mm.

Simiesity. The ratio between thalweg length to down valley distance.

Stage. The height of a water surface above an established datum plane, also gage height.

Standing Waves. Curved, symmetrically shaped waves on the water surface and on the channel bottom that are virtually stationary. When standing waves form, the water and bed surfaces are roughly parallel and in phase.

Stream. A general term for a body of flowing water. In hydrology, the term is generally applied to the water flowing in a natural channel as distinct from a canal. More generally as in the term stream gaging, it is applied to the water flowing in any channel, natural or artificial. Streams in natural channels may be classified as:

Perennial. One which flows continuously.

Intermittent or Seasonal. One which flows at certain times of the year when it receives water from a spring or from some surface source such as melting snow in mountainous areas.

Ephemeral. One that flows only in direct response to precipitation and whose channel is at all times above the water table.

Stream Discharge (Water Discharge). The quantity of natural water passing through a cross section of a stream in a unit of time. (The natural water contains both dissolved solids and sediment.)

Streamline. The line envelope in space of the tangents to the instantaneous flow direction at a given time.

Stream Tube. The surface formed by streamlines passing through a closed curve (which is not a streamline).

Surface Areas, River. The area between the vegetated riverbanks.

Surface Areas, Riverbed. The river surface area less the area of the islands.

Suspended Load. The sediment that is supported by the upward components of turbulent currents in the flow and that stays in suspension for an appreciable length of time.

Tail Water. The water located just downstream from a hydraulic structure on a stream.

Terrace. A berm or discontinuous segments of a berm, in a valley at some height above the floodplain, representing a former abandoned floodplain of the stream.

Thalweg. The line following the deepest part of a streambed, or channel, or valley.

Transition. A category for flows that occur between the lower and upper flow regimes and produce bed forms ranging from those typical of the lower flow regime to those typical of the upper flow regime.

Trap Efficiency. The ability of a reservoir to trap and retain sediment. Expressed as a percent of sediment yield (incoming sediment) which is retained in the reservoir.

Turbidity. The condition of a liquid resulting from fine, visible material in suspension which impedes the passage of light through the liquid.

Two-Dimensional. When applied to mathematical modeling of rivers, the variation of flow, velocity, depth, bottom elevation, etc., is considered in two directions, usually along and perpendicular to the centerline of the river.

Unmeasured (Unsampled Zone). Most suspended-sediment samplers cannot sample within 3 or 4 inches of the streambed. This 3 or 4 inches is called the unmeasured zone in contrast to the measured zone above it.

Upper Flow Regime. A category for flows producing bed forms of plane bed with sediment moving, standing waves, antidunes, or chutes and pools. In the upper flow regime, water-surface undulations are in phase with bed undulations, except in breaking antidune or chute and pool flow.

Wash Load. That part of the total sediment load which is composed of particle sizes finer than those represented in the bed and is determined by available bank and upslope supply rate.

Watershed. The divide separating one drainage basin from another and in the past has been generally used to convey this meaning. However, over the years, the term has been used to signify drainage basin or catchment area although drainage basin is preferred. Drainage divide, or divide, is used to denote the boundary between one drainage area and another. Used alone, the term "watershed" is ambiguous. It should not be used unless the intended meaning is made clear.

Water Year. In U.S. Geological Survey reports dealing with surface-water supply, the 12-month period, 1 October through 30 September. The water year is designated by the calendar year in which it ends and includes 9 of the 12 months. Thus, the year ending 30 September 1959 is the 1959 water year.

APPENDIX D

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